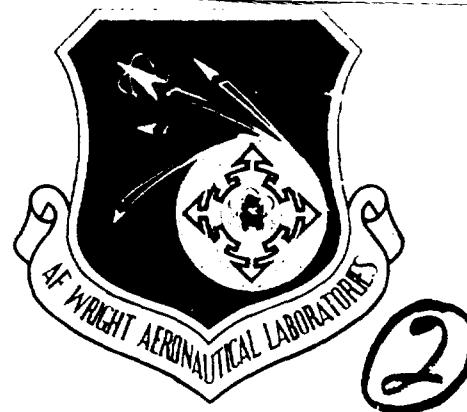AFWAL-TR-83-4125

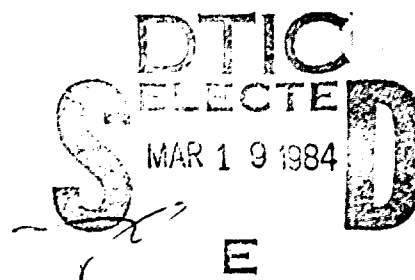HYDROLYTIC DEGRADATION OF KAPTON FILM

D. Robert Askins

UNIVERSITY OF DAYTON RESEARCH INSTITUTE
300 College Park Avenue
Dayton, Ohio   45469

December 1983

Interim Technical Report for the Period:   January 1983 –
July 1983

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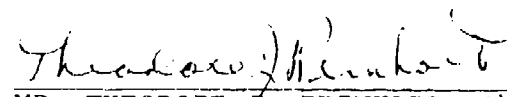MAR 1 9 1984
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| film | tensile | ultraviolet | |
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| hydrolysis | elongation | humidity | |

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*
An investigation of the hydrolytic degradation of Kapton polyimide film has been conducted. Tensile properties were measured on (a) unaged material, (b) material which had been immersed in water at temperatures from 50-100°C for up to 5,000 hours, (c) material which had been stressed to 5,000 psi while being exposed to 95-100% relative humidity at 75° and 85°C, and (d) material which had been repetitively cycled through a combination of ultraviolet radiation and condensing humidity at 50-60°C. The property degradation as a function of time
(Continued)

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20.    Abstract (Concluded)

was found to be best represented by an exponential decay curve for all exposure
conditions.   The immersion time required for the film to lose a prescribed
percentage of its initial tensile properties was determined for each aging
temperature, and these "lifetimes" were correlated with temperature using
the Arrhenius relationship.   Over the temperature range examined, excellent
linearity was obtained.   Following the same criteria as with the immersion
specimen, "lifetimes" were determined for the stressed humidity exposures
and ultraviolet-humidity cyclic exposures.   Both of these exposure environ-
ments significantly accelerated the rate of degradation over that observed
in the unstressed water immersions at equivalent temperatures.

This report covers work performed during the period from January 1983 to July 1983 under Air Force Contract F33615-82-C-5039, Project 7381. The work was administered under the direction of the Systems Support Division of the Air Force Materials Laboratory, Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. Mr. Ed Morrisey (AFWAL/MLSE) was the Program Project Engineer.

The principal investigator on this program was D. Robert Askins. The major portion of the laboratory work was conducted by Messrs. James McKiernan (program scheduling, data compilation and collation, water immersion agings, and QUV-humidity exposures), Don Byrge (mechanical testing), and Dan Miller and Bill Price (stressed humidity agings).

This report was submitted by the author in September 1983. The contractor's report number is UDR-TR-83-95.

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# LIST OF TABLES

# SECTION 1
## INTRODUCTION

Kapton[1] polyimide film is in wide use as a high tem-
perature electrical wire insulation in many military aircraft.
Concern has been raised during recent years that this type of
insulation is susceptible to hydrolytic degradation, leading
to cracks in the insulation which can give rise to electrical
malfunctions.  As a result of this concern, a number of
investigations have been conducted.  Some of these studies
have dealt with insulated wire and have relied on changed
in resistivity or electrical breakdown as a measure of
degradation.  Other investigations have been concerned with
film behavior, relying on changes in film tensile strength or
elongation to measure degradation.

Three previous studies of the hydrolysis of Kapton
film[2-4] developed considerably different kinetic degradation
rate parameters.  While both investigations reported that plots
of retained tensile properties as a function of exposure time
to water exhibited asymptotes after appropriate exposure
periods below which the properties did not fall, they
disagreed on both the level of the asymptote and the rate
at which it was approached.  The Grumman results indicated
a considerably lower initial tensile elongation, a con-
siderably lower asymptotic elongation level, and a considerably
more rapid loss of exposure time.

One purpose of this investigation was to generate
mechanical property data to aid the Air Force in assessing
the relative seriousness of the wire insulation problem.
Secondly, since most of the laboratory data regarding Kapton
film hydrolysis (and accompanying mechanical property
degradation) was obtained by exposing the film to boiling
water (100°C), it was desired to determine whether the

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hydrolytic degradation at lower temperatures could be represented by the standard Arrhenius type relationship, and therefore used to estimate degradation times at other temperatures.

# SECTION 2
## MATERIALS AND TEST PROCEDURES

### 2.1 MATERIALS

All of the material tested during this investigation was supplied by DuPont. It consisted of two, one-half inch wide slit rolls of 100H Kapton polyimide film. These two rolls represent adjacent slit lanes from the same mill roll (No. 00792). The film was 0.001 inch thick. The tensile behavior of this film is very sensitive to edge defects such as nicks or tears.

### 2.2 TENSILE TEST METHODS

All of the test data presented in this report represents the results of room temperature tensile tests on one-half inch wide Kapton film. The tests were conducted either on as-received unaged film or on film aged at one of the various exposure conditions and tested for residual strength.

Each specimen tested, both baseline and after exposure, was five inches long with a two-inch gage section between grips. Specimens were gripped in an Instron test machine with smooth rubber faced pneumatic grips and tested at a crosshead speed of two inches/minute. Figure 1 illustrates a tensile specimen in the Instron grips. Both load and crosshead travel were recorded. Tensile strength was calculated on the basis of constant specimen cross-sectional dimensions of 0.500 inch wide by 0.001 inch thick. Elongation, derived from crosshead travel, was based on an initial specimen gage length of two inches.

All specimens were visually inspected for edge defects, and while very few edge defects were apparent, only specimens with defect free edges were used.

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Figure 1.   Kapton Film Tensile Specimen in Instron Grips.

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In each phase of the program, and for each exposure time within each phase, a sufficient number of replicate tests were conducted to ensure (with two exceptions noted below) that twenty good individual data points could be included in an average value for that particular set of test parameters. A good data point was defined as one deriving from a specimen which, when tested in tension, did not fail at the edge of the grip at an unusually low load and elongation. Thus, a good data point would result from any specimen not failing at a grip edge or from a specimen which did fail at a grip edge but at a load or elongation equal to or above the average for all the other replicate samples within the set.

Generally, the entire sample set for any one set of conditions consisted of 24-46 specimens. The first twenty "good" test results were used in the average values presented in the following tables. The appendix presents tabulations of the complete test data.

There were two exceptions to the above statement that at least twenty "good" data points are incorporated into each average value presented in the subsequent sections. These exceptions were for the stressed agings described in Section 5.2. In each case, over 40 specimens were under test at the beginning of the stressed exposure period, but so many failed during exposure that fewer than 20 survived for residual strength testing.

2.3    EXPERIMENTAL OUTLINE

The program was subdivided to form different work phases. These were as follows:

    (a) Baseline Control Tests on Unaged Film,

    (b) Unstressed Water Immersion Exposures,

    (c) Stressed Humidity Exposures, and

    (d) Unstressed Humidity-Ultraviolet Exposures.

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The baseline test phase involved the generation of tensile data on unaged Kapton film, while the other three involved various environmental exposure conditions followed by residual film tensile tests for comparison to the baseline data. Each of these are described in more detail in Sections 3 and 4.

## 2.4    THEORETICAL BASIS FOR TREATMENT OF DATA

Hydrolytic degradation has been investigated for a variety of different types of polymeric materials and the data analyzed kinetically. Welch and Lofgreen[5] examined the humidity aging of elastomeric potting compounds and determined that the reaction (reversion) rate could be satisfactorily represented as a first order reaction with respect to water vapor concentration, and that the use of the Arrhenius relationship permitted prediction of service life (arbitrarily defined) for different temperatures. Berner[6] studied a polyester mat and a polyester polyurethane foam. He also found that the reaction rate was a first order function of water vapor concentration and that service life could be predicted from accelerated laboratory tests using the Arrhenius relationship.

The studies cited above were conducted by exposing the polymeric materials to a matrix of environmental conditions consisting of various temperatures and relative humidity levels. In analyzing the experimental results, the assumption was made that since the polymer concentration was the same in all of the different exposure conditions, it could be treated as a constant in the rate equation. Further, the assumption was made that the reaction rate was constant throughout the period of hydrolysis. While this assumption is reasonable for short periods, its validity over long time periods is questionable.

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In this investigation, the controlled test parameter was exposure temperature. In the water immersion tests, the water concentration external to the specimens was constant. The water concentration level within the film may depend on immersion temperature and is probably higher for the higher immersion temperatures than for the lower temperatures.

Germeraad and Cornelius[4] demonstrated the presence of chemically reactive sites in Kapton film which were susceptible to hydrolytic attack and suggested that they were the result of incomplete polyimide cyclization or the presence of small amounts of isoimide. Thus, a variety of different types of chain scission sites are present in Kapton film, each in its own particular concentration. Since we have no idea which type of site, if any, predominates, nor are the particular kinetics of hydrolysis of the different types of reactive sites known, the overall hydrolytic degradation rate is most readily considered as some sort of average overall reaction.

The hydrolysis process is believed to consist of a period of diffusion of water into the one mil thick film until an equilibrium absorbed moisture content is achieved. During this preequilibrium period, the hydrolysis reaction rate is probably dependent upon both the water concentration and the concentration of available chain scission sites within the Kapton film, as well as the particular kinetics for each type of available chain scission site. Once equilibrium water diffusion into the film is achieved, the water concentration within the film becomes constant, although this constant level may be dependent upon temperature. In-house studies[7] of liquid absorption by polyimide film indicate that the time required to reach equilibrium diffusion is negligible in comparison to the length of time over which exposures were conducted here. Hence, the hydrolysis reaction rate becomes essentially a function only of the concentration of available chain scission sites.

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Following this reasoning and utilizing some sort of average overall reaction as representative of the bulk polymer behavior, one best represents the reaction rate mathematically as:

$$\bar{r}_s = - \frac{d\bar{c}_{ss}}{dt} = k_1 \bar{c}_{ss}^{-n} \tag{1}$$

where:

$\bar{r}_s$ = average rate at which chain scission sites are undergoing hydrolytic scission (scissions/hr)

$\bar{c}_{ss}$ = average concentration of various types of chain scission sites (sites/liter)

$k_1$ = average chain scission rate constant, dependent on temperature

$n$ = average order of the reaction with respect to the various types of chain scission sites.

Wallach[8] has presented data indicating that a nearly linear relationship exists between tensile strength and elongation and molecular weight of polyimide over the range of strength and elongation changes of concern in this program. Thus, as chain scission progresses and average molecular weight decreases, tensile properties decrease in concert with the reaction rate, and it can be reasoned that the rate of change of the film tensile properties can be described by an equation of the same form as (1), i.e.,

$$- \frac{d\,(UTS)}{dt} = k_2\,(UTS)^n \tag{2}$$

where:

UTS = ultimate tensile strength

$k_2$ = rate constant dependent on temperature [as in equation (1)]

The order of reaction is determined most easily by integrating equation (2) for various values of n, fitting the data to the various types of curves which result and determining which fits best. A zero order reaction would yield a straight line. A first order reaction yields an

exponential decay curve. A second order reaction produces
a curve with the same general shape as the exponential
decay curve. There is no basis, however, for the hydrolysis
reaction to be higher order since the chain scissions
involve the breaking of a single bond each. Further,
the previous work cited on hydrolytic degradation of
various types of polymers found that the reactions were
always first order. The experimental data obtained in this
investigation was fitted to the equations which result for
n = 0, 1, and 2, and it was found that the exponential
decay form for n = 1 did indeed provide the best fit. Thus,
integration of equation (2) for n = 1 yields

$$\int \frac{d(UTS)}{UTS} = \int k_2 dt$$

$$\ln(UTS) = k_2 t + c$$

where:

   c = constant of integration.

In exponential form,

$$UTS = \frac{1}{c} e^{-k_2 t} = c' e^{-k_2 t} \qquad (3)$$

where:

   c' = UTS when t = 0.

Thus, all of the residual tensile strength and elonga-
tion data obtained for the various exposure conditions
during this program have been fitted to exponential decay
curves. These curves are plotted along with the experimental
data in the subsequent figures.

A "lifetime" for each exposure condition was defined
as that time at which the residual tensile strength and
elongation fell below 80% and 50%, respectively, of the
original baseline values. These two lifetimes occurred at
about, but not exactly at, the same aging time. These life-
times were correlated with temperature using the Arrhenius
relationship. Thus, from equation (3):

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$$UTS^* = UTS_O \, e^{-k_2 t^*}$$

$$\frac{UTS^*}{UTS_O} = e^{-k_2 t^*}$$

where:

$t^*$ = aging time required for residual tensile strength or elongation to fall to 80% or 50%, respectively, of initial value.

$UTS_O$ = original ultimate tensile strength at $t = 0$

$UTS^*$ = ultimate tensile strength when $t = t^*$

for $\dfrac{UTS^*}{UTS_O} = 0.8$ (definition of lifetime)

$e^{-k_2 t} = 0.8$, or in logarithmic form

$$-k_2 t^* = \ln 0.8 = -0.22314 \qquad (4)$$

where * indicates values when lifetime is reached, as: $UTS^* = 0.8 \, UTS_O$, $t^* =$ time for UTS to decay to $UTS^*$.

From the Arrhenius relationship

$$k_2 = Ae^{-E_a/RT} \qquad (5)$$

where:

A = frequency factor

$E_a$ = activation energy

R = gas constant

T = temperature (absolute).

Combining equations (4) and (5),

$$-Ae^{-E_a/RT} t^* = -0.22314 \qquad (6)$$

$$t^* = \left(\frac{0.22314}{A}\right) e^{E_a/RT}$$

Logarithmically,

$$\log t^* = \log \left(\frac{0.22314}{A}\right) + \frac{E_a}{2.3 \, RT} \qquad (7)$$

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For the water immersion tests the log of the lifetime
was plotted against the reciprocal temperature, and excellent
linearity was obtained. These plots are presented and dis-
cussed in Sections 4-6.

# SECTION 3
## BASELINE CONTROL TESTS

Baseline tensile tests were conducted on each of the two rolls of Kapton film supplied by DuPont. Although tensile tests were conducted on both rolls of film received from DuPont, since all specimens used throughout the program were taken from the roll designated "C", the tensile properties for this roll were used as the baseline reference values for all residual property tests.

Table 1 presents the as-received tensile properties of each roll of Kapton film along with data obtained and supplied by DuPont for samples taken from the same mill roll but from adjacent slit lanes.

It is apparent that there is excellent agreement between UDRI and DuPont measurements of tensile strength, with all six values in Table 1 falling within 5% of the overall average of 34,200 psi (236 MPa). Tensile elongation data on the other hand exhibits some inexplicable disparities. The UDRI results are markedly lower than the DuPont values. The overall DuPont average elongation of 67.9% is about 25% higher than the overall UDRI average value of 53.6%. While the reason for this discrepancy is uncertain, it is probably due to a difference in procedure or interpretation. Since all of our results will be referenced to the baseline values as a percent-of-original, and the same procedures and methods of interpretation will be common to all data, it was not felt that the exact reason for the UDRI-DuPont elongation differences was worth pursuing.

# TABLE 1

## TENSILE PROPERTIES OF FRESH, UNAGED KAPTON FILM

| Data Source | Tensile Strength | | | | Tensile Elongation | |
|---|---|---|---|---|---|---|
| | Average | | Standard Dev. | | Average | Standard Dev. |
| | (psi) | (MPa) | (psi) | (MPa) | (%) | (%) |
| DuPont, roll "A", location 1 | 34,200 | 236 | 2,000 | 14 | 66.7 | 10.2 |
| DuPont, roll "A", location 2 | 33,600 | 232 | 1,300 | 9 | 69.5 | 7.8 |
| DuPont, roll "A", location 3 | 35,600 | 245 | 1,500 | 10 | 73.7 | 8.0 |
| DuPont, roll "B"[1] | 34,800 | 240 | 2,600 | 18 | 61.8 | 11.4 |
| UDRI, roll "C"[2,3] | 34,500 | 238 | 2,000 | 14 | 54.2 | 9.0 |
| UDRI, roll "D" | 32,600 | 225 | 2,600 | 18 | 52.9 | 11.8 |

[1] Values represent averages of ten samples each.

[2] Values represent averages of twenty samples each.

[3] Values for this roll are used as baseline reference values for percent retention values reported in Sections 4 through 6.

SECTION 4

UNSTRESSED WATER IMMERSION EXPOSURES

## 4.1 EXPOSURE AND TEST PROCEDURE

Unstressed water immersion tests were conducted at
six different temperatures ranging from 50°C to 100°C.
Long, continuous strips of Kapton film were taken from
roll "C" and loosely wound, along with a continuous strip
of fiberglass fabric, into a spool. The glass fabric
served as a separator strip to ensure that water penetrated
between each wrap of the film. This film-fiberglass spool
is illustrated in Figure 2. This spool was placed in a
beaker and covered with deionized water. The beaker was
covered and placed in a circulating air oven at the desired
exposure temperature. Oven temperature was monitored daily
by multiple indicators to ensure proper control.

After prescribed aging periods, the beaker was removed
from the oven, and residual tensile tests were conducted.
Individual specimens were cut from the film spool with scissors
and tested immediately. Between tests, the film spool was
returned to the water filled beaker at room temperature to
prevent dryout.

## 4.2 DISCUSSION OF RESULTS

Table 2 indicates the time-temperature test matrix
followed for all of the various types of exposures discussed
in Section 3 through 4 and also presents the results
obtained. Figures 3 and 4 present the plots of residual
strength and elongation as functions of immersion time
at the various exposure temperatures. As discussed in
Section 2.4, least square fits of the data to exponential
decay curves are also drawn in and the lifetime identified
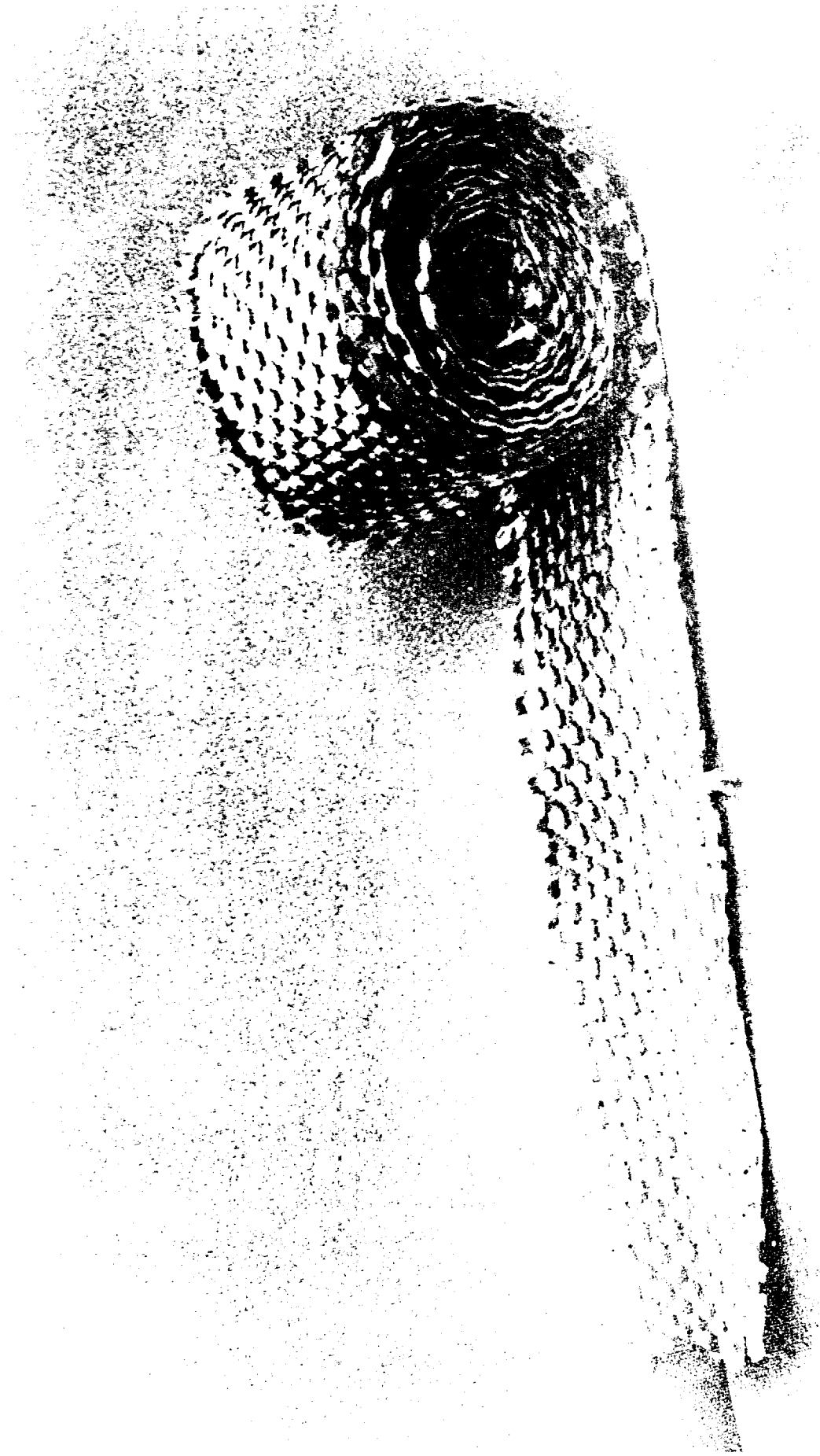for each temperature.

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Figure 2. Kapton-Fiberglass Spool for Unstressed Water Immersion Exposures.

TABLE 2

EFFECT OF EXPOSURE TO VARIOUS ENVIRONMENTS ON ROOM TEMPERATURE
TENSILE PROPERTIES OF KAPTON FILM

| Exposure Condition | Exposure Temperature (°C) (°F) | Exposure Time (hrs) | Tensile Strength | | | | Ultimate Elongation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Average (ksi) (MPa) | Std. Dev. (ksi) (MPa) | | % of Baseline | Average (%) | Std. Dev. (%) | % of Baseline |
| No Exposure - Baseline | N.A. | N.A. | 34.5 (238) | 2.0 | (14) | 100 | 54.2 | 9.0 | 100 |
| Unstressed Water Immersions | 100 (212) | 24 | 31.6 (218) | 1.9 | (13) | 92 | 43.6 | 6.8 | 80 |
| | | 112 | 28.0 (193) | 1.6 | (11) | 81 | 33.0 | 7.0 | 61 |
| | | 184 | 28.2 (194) | 1.2 | ( 8) | 82 | 27.9 | 4.1 | 51 |
| | | 376 | 26.5 (183) | 1.3 | ( 9) | 77 | 24.7 | 4.3 | 46 |
| | 90 (185) | 200 | 29.8 (205) | 1.0 | ( 7) | 86 | 40.5 | 4.8 | 75 |
| | | 600 | 26.5 (183) | 0.9 | ( 6) | 77 | 26.2 | 3.5 | 48 |
| | 75 (167) | 300 | 30.6 (211) | 1.5 | (10) | 89 | 42.0 | 7.8 | 77 |
| | | 600 | 29.5 (203) | 1.3 | ( 9) | 86 | 37.8 | 6.1 | 70 |
| | | 1000 | 27.8 (192) | 0.9 | ( 6) | 81 | 30.3 | 4.2 | 56 |
| | 70 (158) | 500 | 31.0 (214) | 2.0 | (14) | 90 | 45.9 | 10.2 | 85 |
| | | 1000 | 28.7 (198) | 1.7 | (12) | 83 | 37.7 | 7.6 | 70 |
| | | 1500 | 27.6 (190) | 1.1 | ( 8) | 80 | 29.9 | 5.3 | 55 |
| | 60 (140) | 750 | 29.4 (206) | 1.4 | (10) | 87 | 41.9 | 6.8 | 77 |
| | | 1500 | 28.5 (196) | 1.5 | (10) | 83 | 32.8 | 7.1 | 61 |
| | | 2250 | 27.7 (191) | 1.2 | ( 8) | 80 | 29.9 | 5.6 | 55 |
| | | 3000 | 26.7 (184) | 1.2 | ( 8) | 77 | 27.1 | 5.0 | 50 |
| | | 4000 | 26.7 (184) | 2.3 | (10) | 77 | 21.6 | 5.7 | 40 |
| | 50 (122) | 1000 | 30.6 (211) | 2.0 | (14) | 89 | 45.2 | 6.7 | 83 |
| | | 2000 | 30.3 (209) | 1.5 | (10) | 88 | 42.1 | 7.7 | 78 |
| | | 3550 | 28.9 (199) | 1.6 | (11) | 84 | 36.9 | 7.2 | 68 |
| | | 5000 | 26.6 (183) | 1.2 | ( 8) | 77 | 25.4 | 4.8 | 47 |
| Stressed Humidity Exposures, 5000 psi (34.5 MPa), 95-100% R.H. | 85 (185) | 200 | 28.7 (198) | 2.6 | (18) | 83 | 31.0 | 8.1 | 57 |
| | | 400 | 27.0 (186) | 1.4 | (10) | 78 | 20.9 | 5.1 | 39 |
| | 75 (167) | 300 | 29.6 (204) | 1.1 | ( 8) | 86 | 32.9 | 7.0 | 62 |
| | | 600 | 27.6 (190) | 3.7 | (25) | 80 | 26.5 | 8.7 | 49 |
| Unstressed Humidity Ultraviolet Exposure (see description in text) | 55- (131-60) 140) | 200 | 32.1 (221) | 1.4 | (10) | 93 | 48.6 | 6.6 | 90 |
| | | 500 | 28.4 (196) | 1.5 | (10) | 82 | 33.0 | 8.5 | 61 |
| | | 1000 | 23.5 (162) | 0.8 | ( 6) | 68 | 18.6 | 2.0 | 34 |
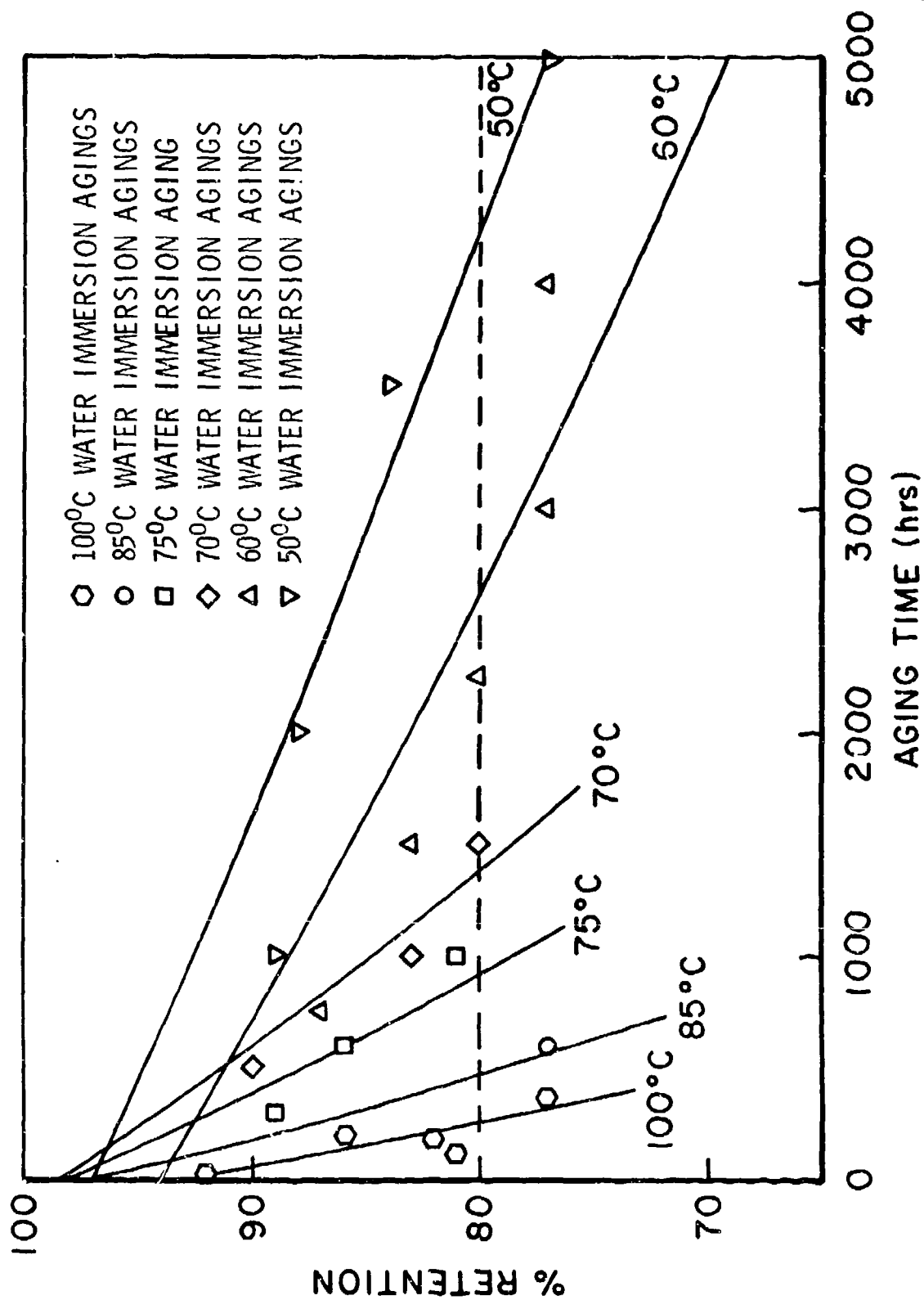
Figure 3. Effect of Unstressed Environmental Aging on Retention of Tensile Strength of Kapton Film.

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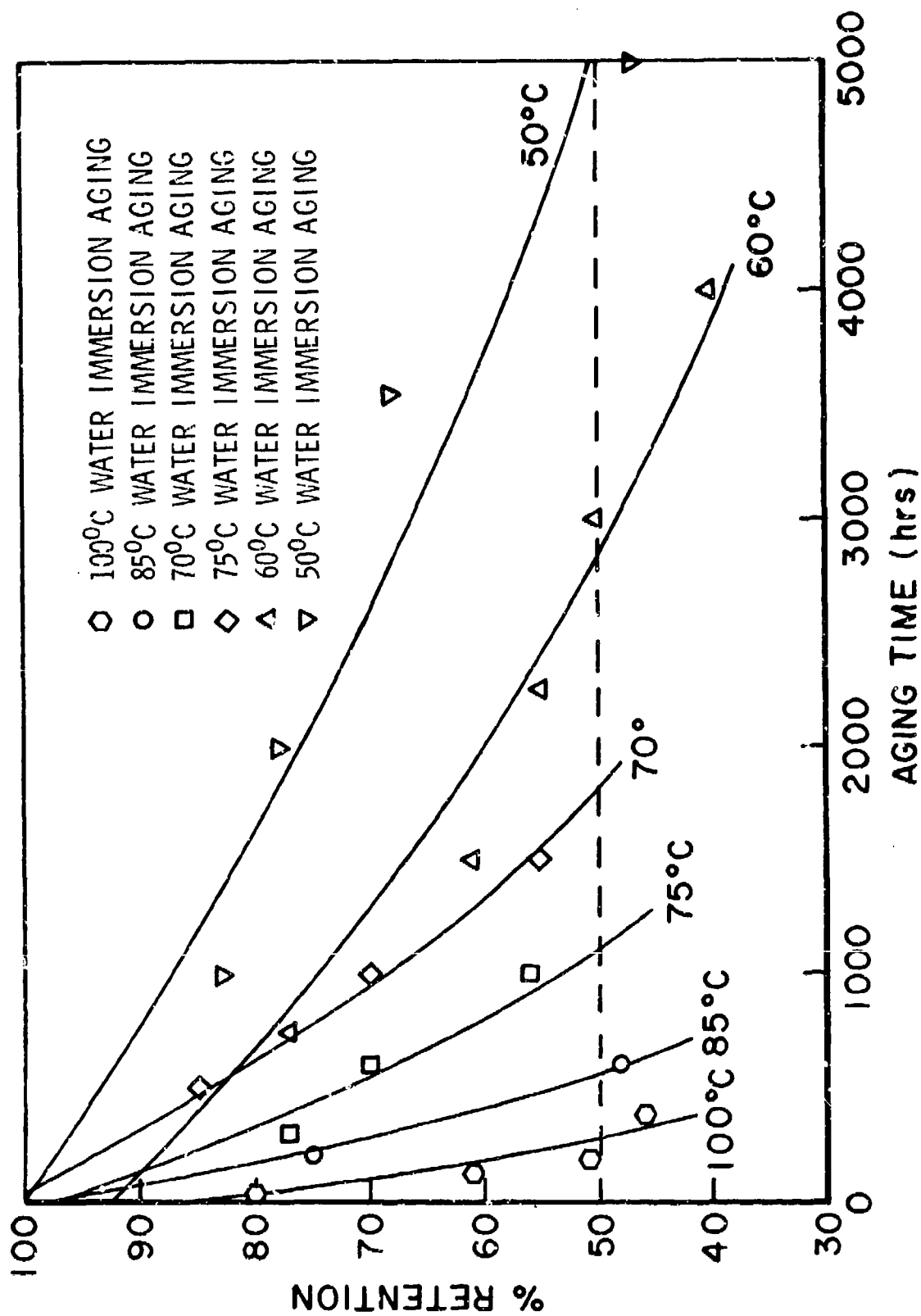
Figure 4. Effect of Unstressed Environmental Aging on Retention of Tensile Elongation of Kapton Film.

The effect of temperature upon the hydrolytic degradation of Kapton film is illustrated in Figures 5 and 6, where the Arrhenius relationship between lifetime (as defined here) and temperature is plotted. Figures 5 and 6 include data from references 2 and 3. It is apparent from the excellent linearity of the data that the Arrhenius relationship well represents the hydrolysis reaction of Kapton film over the temperature range of 50-100°C, and could probably be used to estimate lifetime at temperatures somewhat lower than these limits with reasonable confidence.
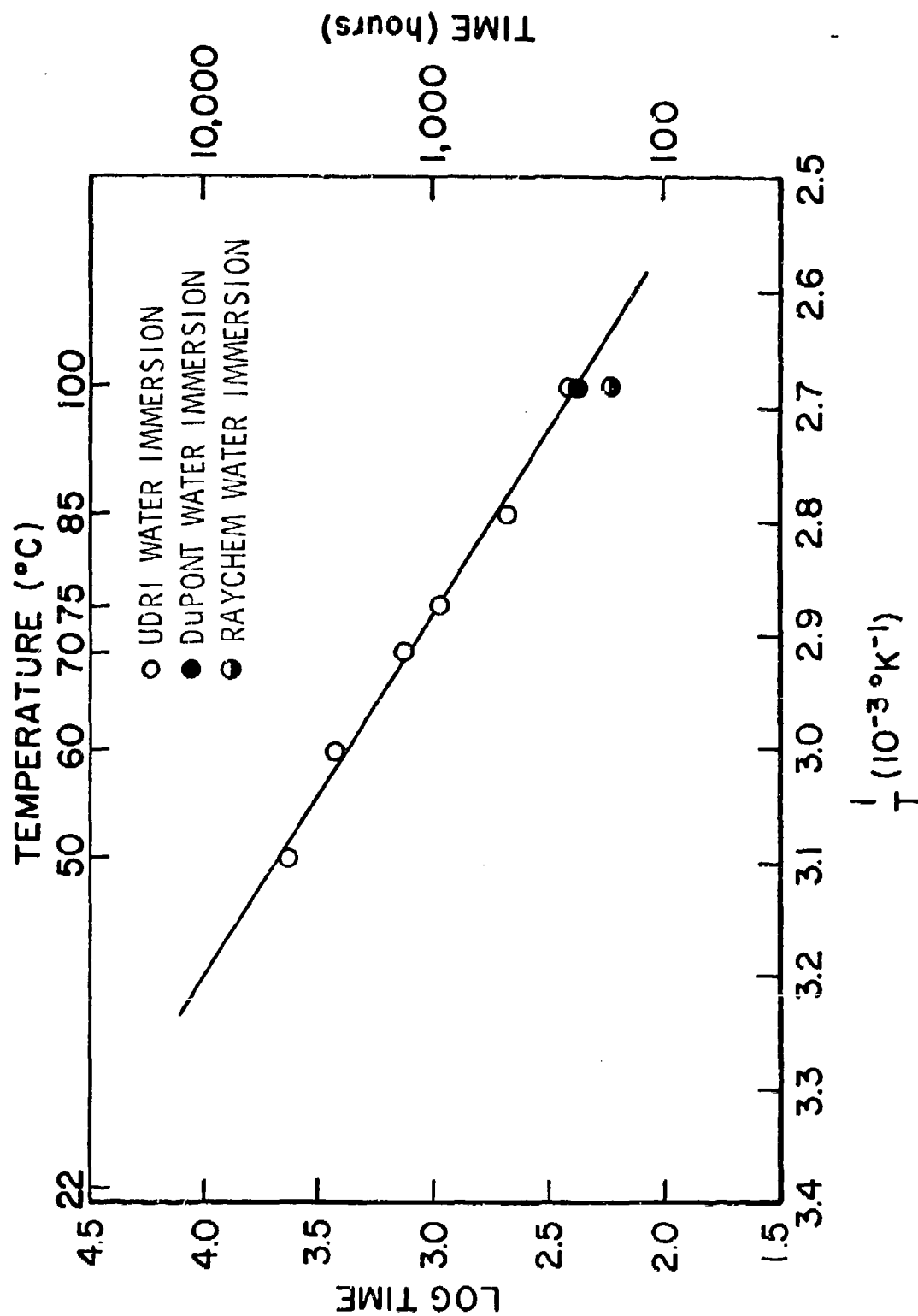
Figure 5. Effect of Temperature Upon Lifetime (20% Decrease in Tensile Strength) of Kapton Film.
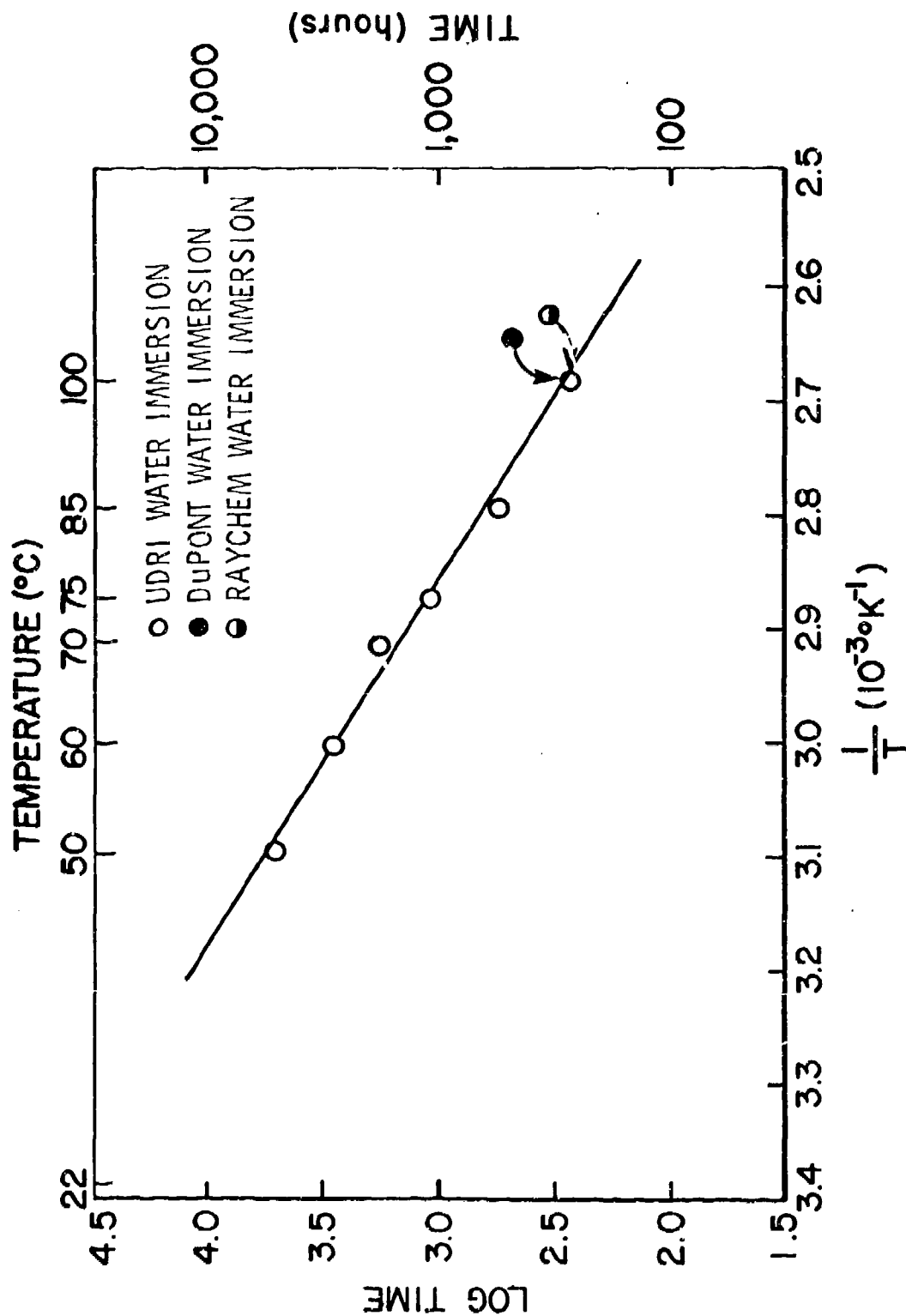
Figure 6. Effect of Temperature Upon Lifetime (50% Decrease in Tensile Elongation) of Kapton Film.

# SECTION 5

## STRESSED HUMIDITY EXPOSURES

### 5.1 EXPOSURE AND TEST PROCEDURE

Stressed humidity exposures were conducted at two different temperatures, 75°C (167°F) and 85°C (185°F). All of the exposures were at 95-100% relative humidity (RH) and all of the specimens were under 5000 psi (34.5 MPa) stress throughout the prescribed exposure periods. Twenty inch strips of Kapton film were gripped and loaded as shown in Figure 7 during the exposures.

The humidity cabinet housing the specimens was checked daily for broken specimens. Subject to space limitations within the humidity cabinets, about forty to fifty specimens were started for each prescribed combination of time and temperature. At the shorter aging times, a sufficient number of specimens survived to provide an average residual strength value based on twenty "good" tensile tests (the definition of a "good" failure was presented in Section 2.2). At the longer aging times, so many specimens broke before completion of the aging period that average residual strength values had to be based on less than twenty tests. The times at which each aging failure occurred were recorded but are not presented or discussed here.

### 5.2 DISCUSSION OF RESULTS

The residual property data obtained for these stressed-humidity exposures are presented in Table 2. Figures 8 and 9 illustrate these results graphically and also include the results for the unstressed water immersion exposures conducted at the same temperatures. It is

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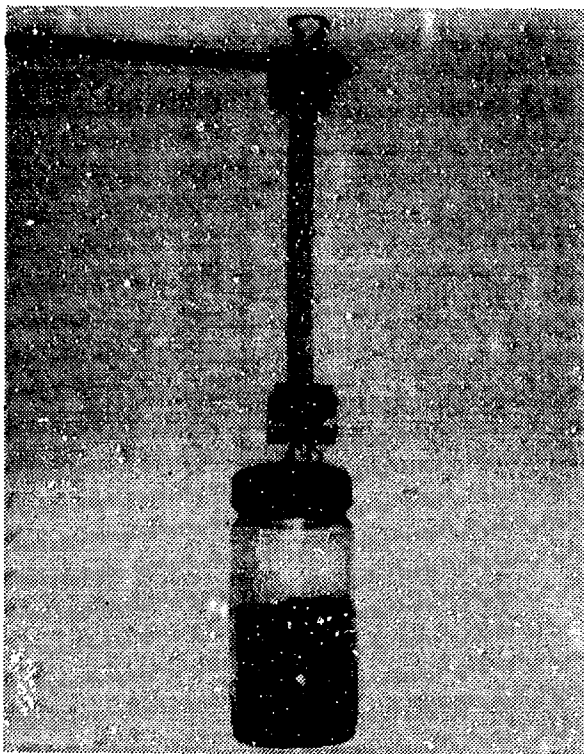
(a) Stressed Kapton Sample for Humidity Aging.
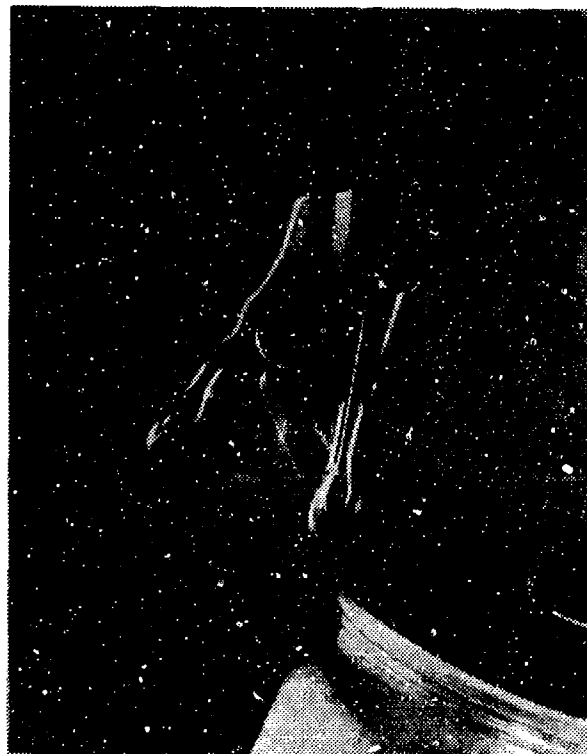


(b) Close-up of Grip Used in Humidity Cabinet for Stressed Kapton Sample.
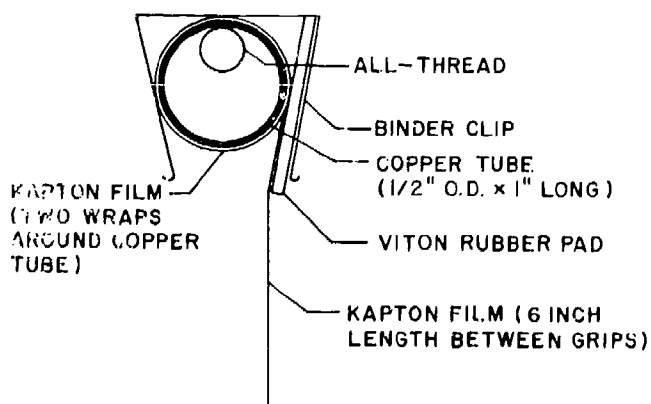


(c) Schematic of Grip Used in Humidity Cabinet for Stressed Kapton Sample.

Figure 7. Method of Gripping and Loading Kapton Film During Stressed Humidity Exposures.
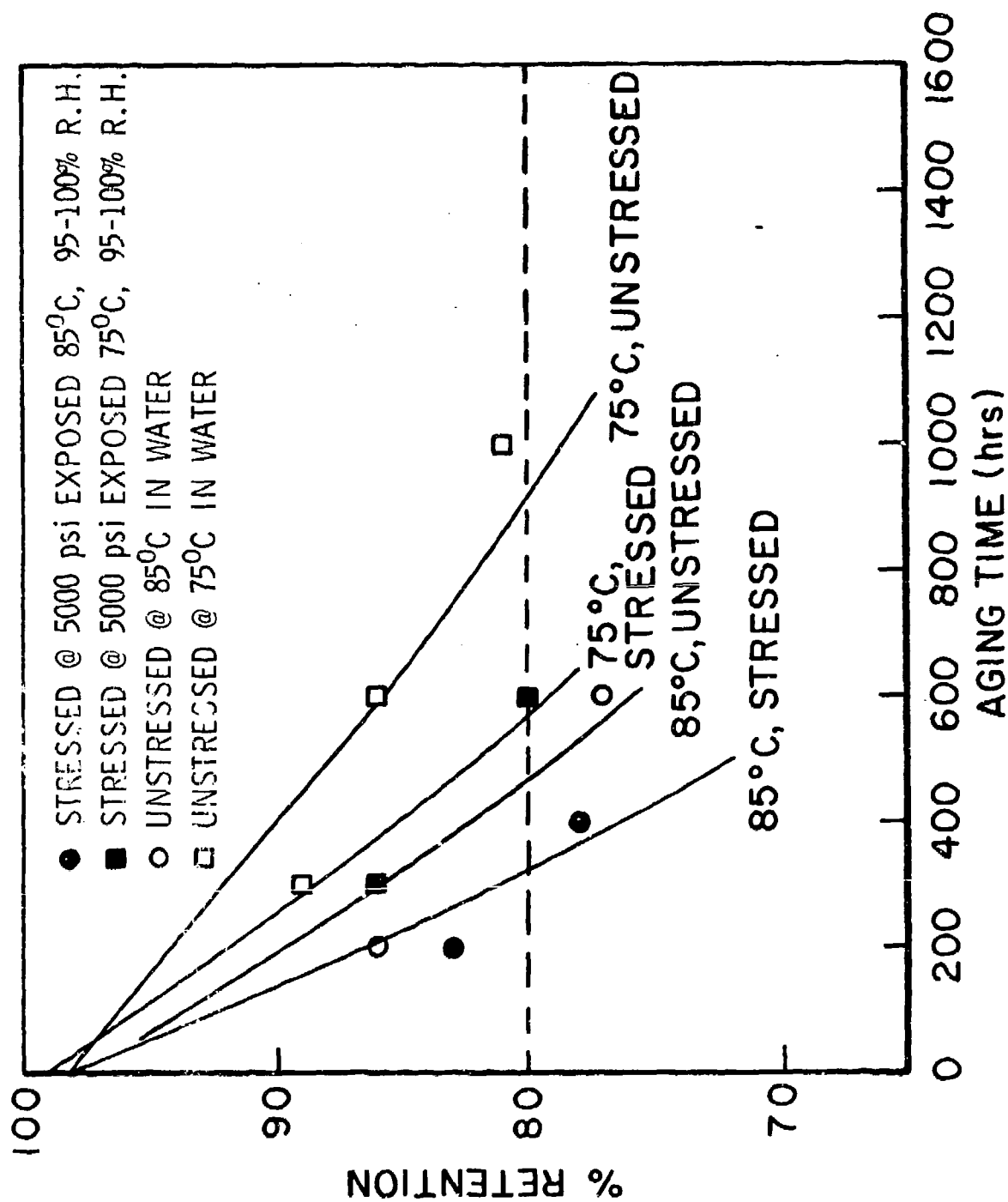
Figure 8.  Effect of Stressed vs. Unstressed Environmental Aging on Tensile
Strength Retention of Kapton Film.

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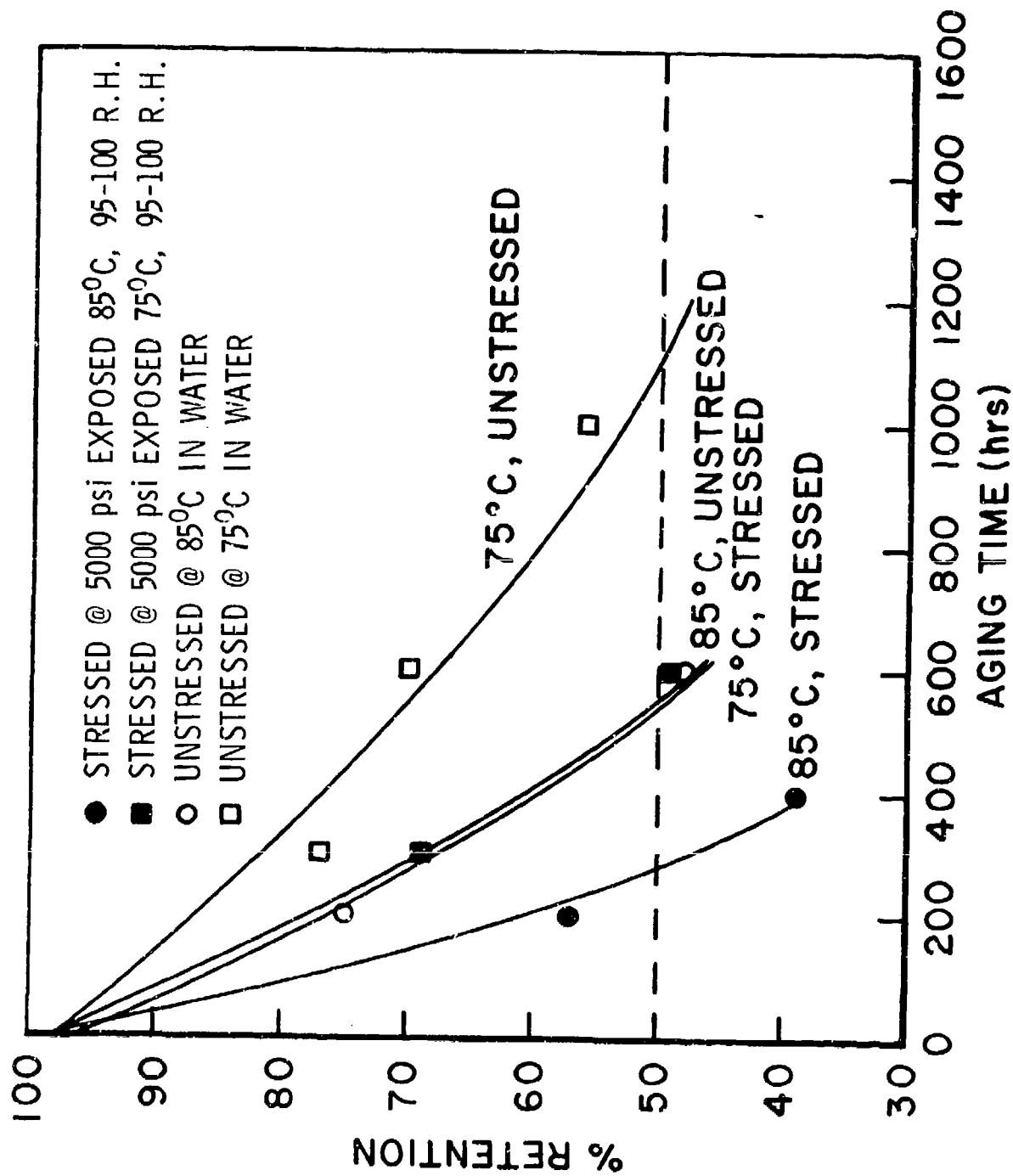
Figure 9. Effect of Stressed vs. Unstressed Environmental Aging on Retention of Tensile Elongation of Kapton Film.

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apparent that the property degradation of the stressed-
humidity specimens occur more rapidly than the unstressed
water immersion specimens. The lifetimes (as defined
previously) of the stressed-humidity specimens are only
50-75% (depending on whether strength or elongation loss
is compared) of the unstressed water immersion lifetimes
for equivalent temperatures. Figures 10 and 11 illustrate
the position of the stressed-humidity data relative to
the unstressed water immersion data on an Arrhenius plot.
It can be seen from this figure that the acceleration in the
rate of hydrolytic degradation observed in the stressed-
humidity condition is equal to that which would be caused
by an increase of about 10°C in the unstressed water
immersion condition. Since the slope produced by the two
stressed-humidity points is equivalent to that exhibited
by the water immersion data, it can be concluded that the
effect of temperature on the hydrolysis reaction rate is
unaffected by the presence of mechanical stress or by the
concentration of the water in the exposure environment.
This latter observation is probably due to the fact
that the reaction rate depends upon absorbed moisture
concentration, and at equivalent temperatures, the equi-
librium absorbed moisture content is equivalent for a
water immersion or condensing humidity environment; the
difference being reflected only in the relative length
of time required to reach the equilibrium absorbed moisture
content.

Figure 10. Effect of Temperature Upon Lifetime (20% Decrease in Tensile Strength) of Kapton Film.

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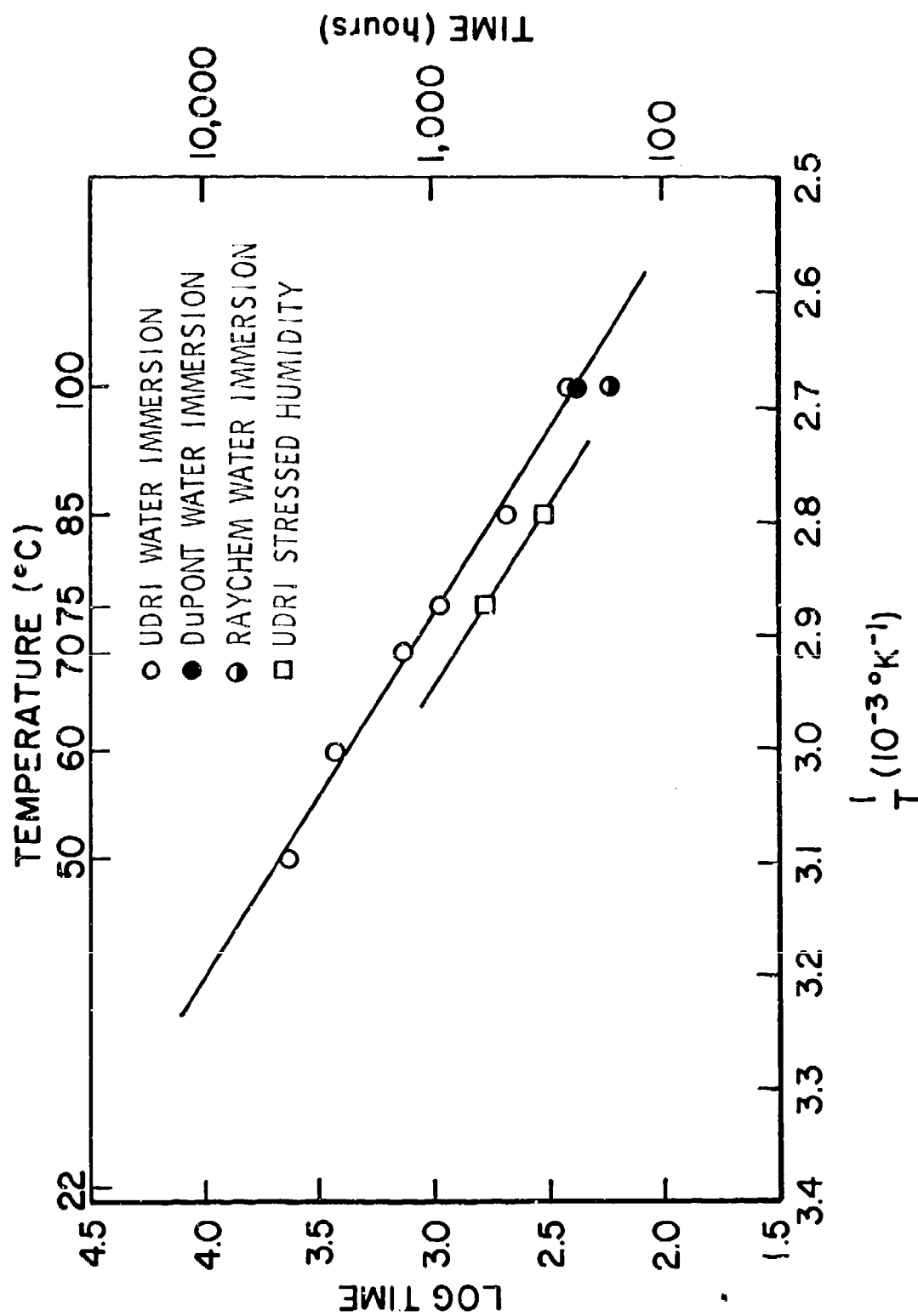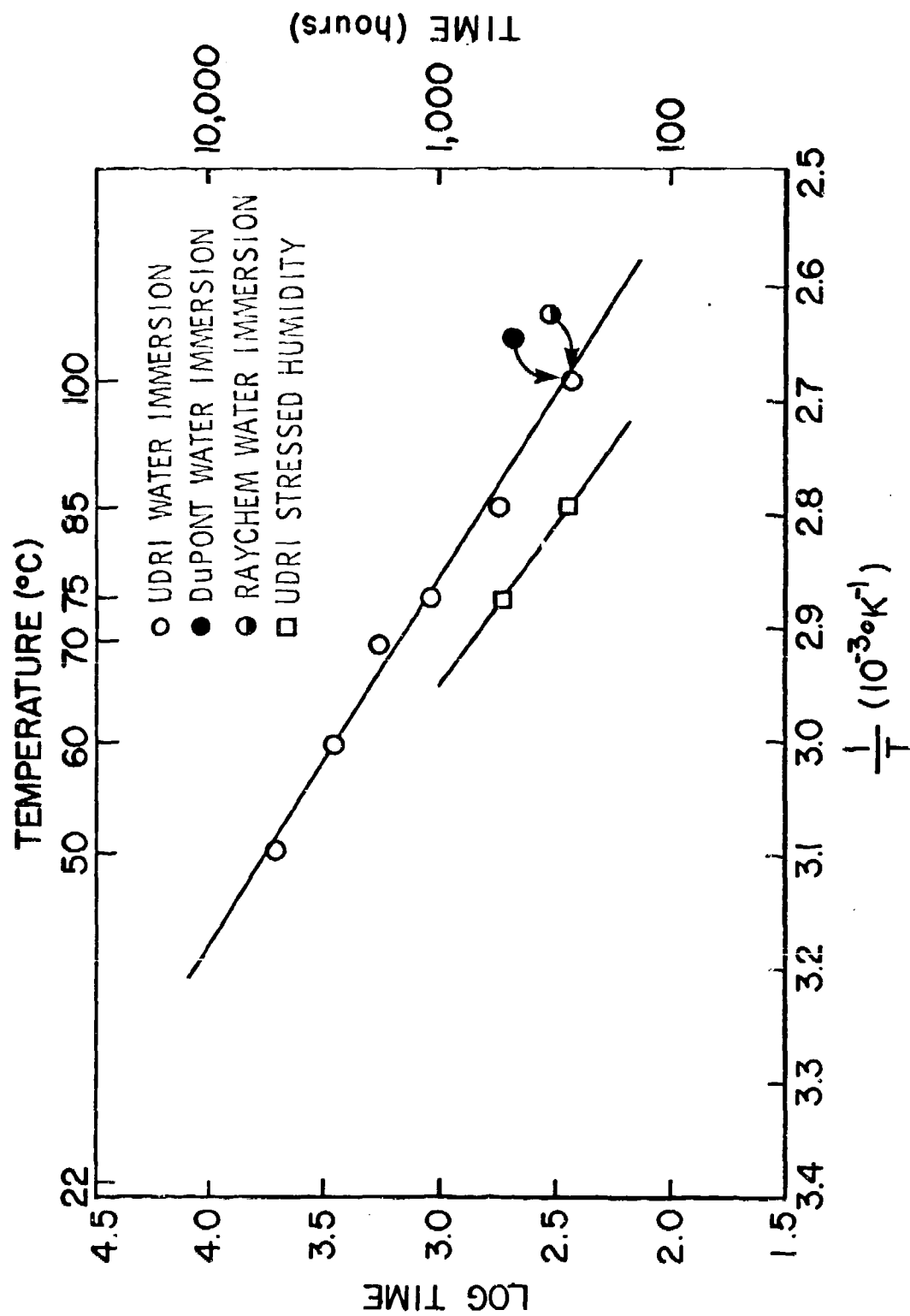Figure 11. Effect of Temperature Upon Lifetime (50% Decrease in Tensile Elongation) of Kapton Film.

SECTION 6

UNSTRESSED HUMIDITY-ULTRAVIOLET EXPOSURES

6.1    EXPOSURE AND TEST PROCEDURE

Unstressed humidity-ultraviolet exposures were conducted in a QUV Accelerated Weathering Tester. This apparatus can be programmed to provide a 24 hour cycle comprised of any desired ratio of alternating ultraviolet (UV) light irradiation and condensation. The exposures conducted during this investigation utilized a 4 hour condensation - 8 hour UV cycle. The temperature throughout the 8-hour UV cycle was maintained between 50°C and 55°C (122°F and 131°F), except for the first 1/4-hour, during which time the temperature fell from the 56-62°C range (134-43°F) to the equilibrium range. When the UV cycle ends and the condensation cycle starts, the temperature decreased over a 1/2-hour period to about 41°C (105°F), then recovered over a 1 1/2-hour period to between 56°C and 62°C (134°F and 143°F), where it remained for the remaining 2 hours of the 4 hour cycle. Figure 12 illustrates a typical 24 hour QUV temperature record. Figure 13 illustrates the QUV test cabinet and specimen exposure arrangment.

6.2    DISCUSSION OF THE RESULTS

The residual property data for the QUV exposed specimens is presented in Table 2 and illustrated in Figures 14 and 15 , alongside the results for the unstressed water immersion specimens exposed at 60°C. It is readily noted that the property degradation of the Kapton film occurs much more rapidly in the cyclic QUV exposure environment then in a water immersion environment at an equivalent or slightly higher temperature.

Figure 12.   Typical 24 Hour QUV Cabinet Temperature Record.
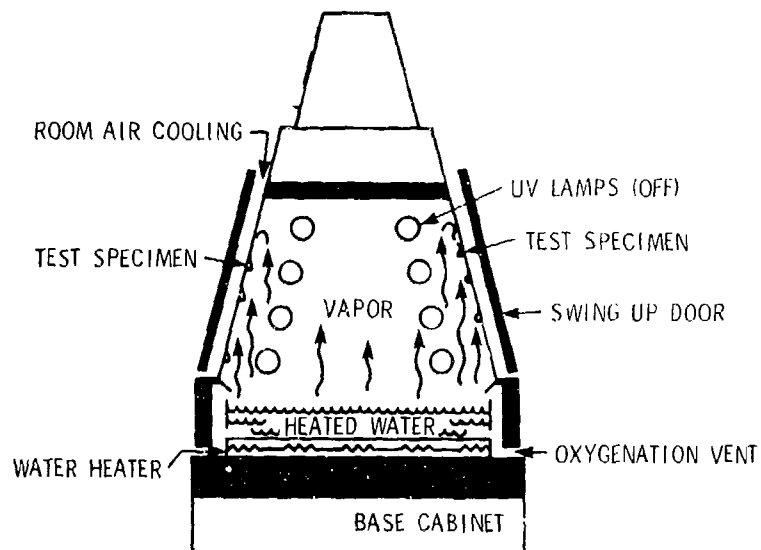
(a) Simplified Cross-Section of QUV Cabinet (Condensation Period Illustrated)



(b) Mounting of Kapton Film Strips on Test Specimen Rack in QUV Cabinet.

Figure 13.  QUV Accelerated Weathering Test Cabinet and Specimen Arrangement.
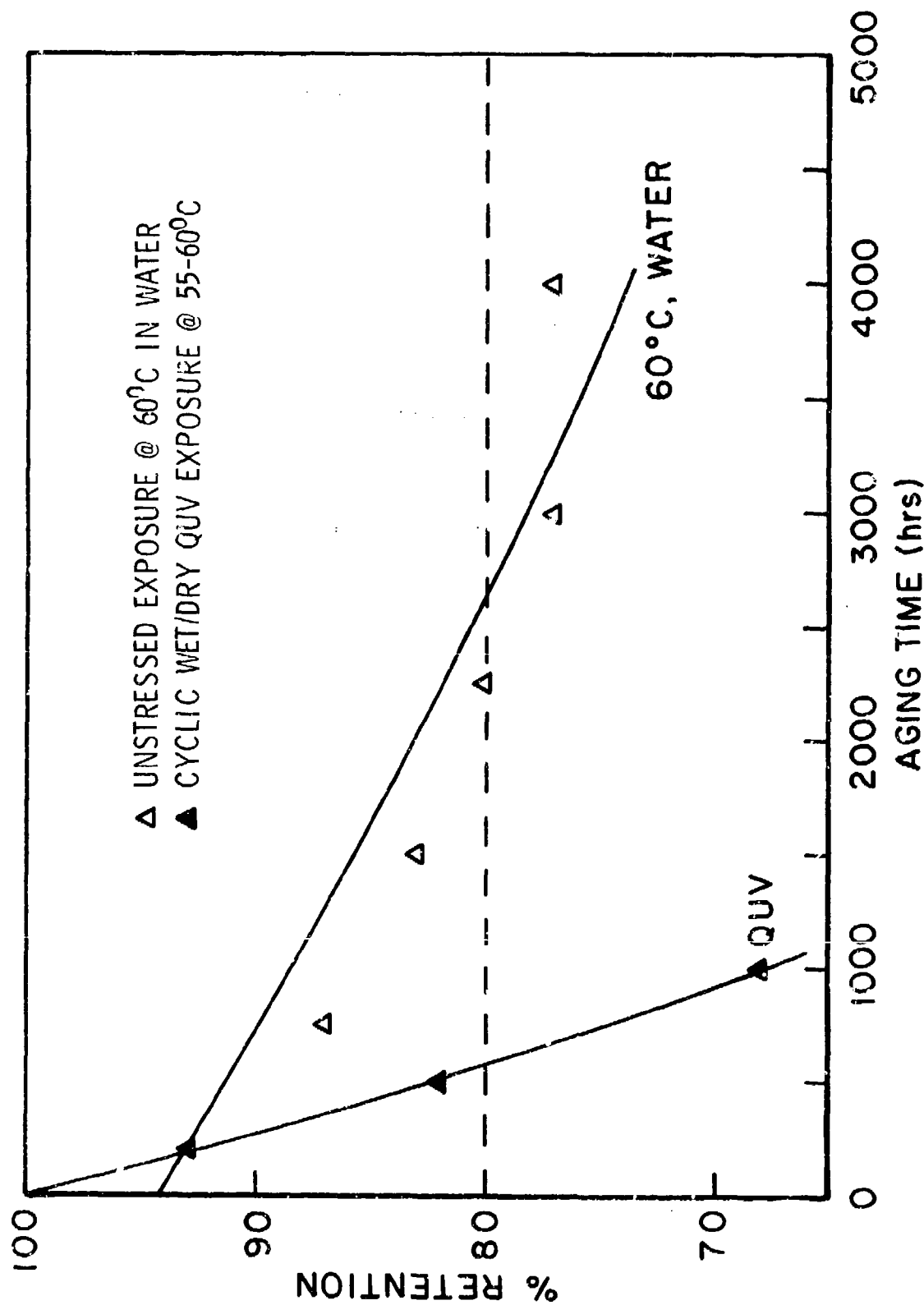
Figure 14. Effect of Unstressed Environmental Aging @ 60°C in Water vs. Cyclic Wet/Dry QUV Exposure @ 55-60°C on Retention of Tensile Strength of Kapton Film.
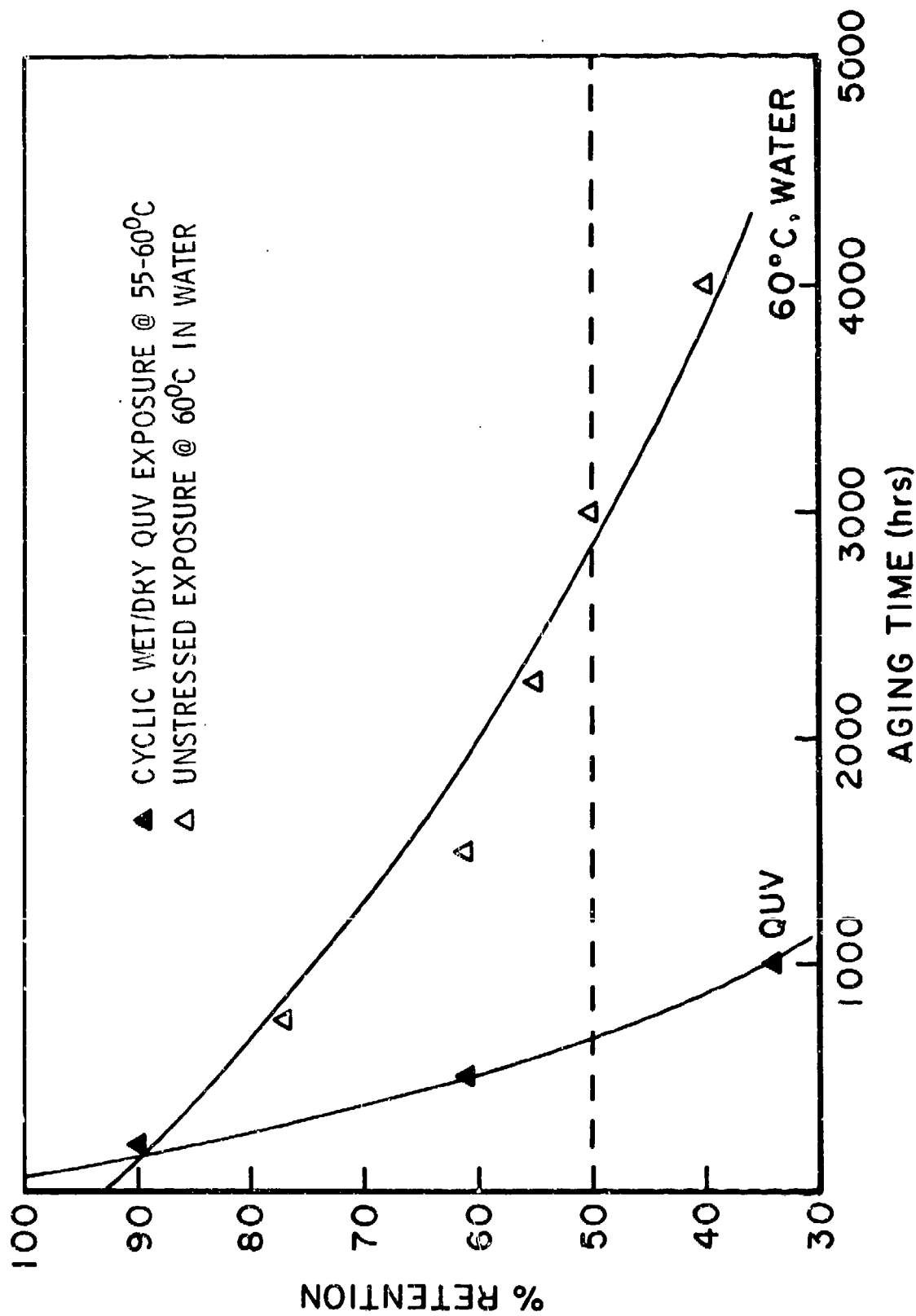
Figure 15. Effect of Unstressed Environmental Aging @ 60°C in Water vs. Cyclic Wet/Dry QUV Exposure @ 55-60°C on Retention of Tensile Elongation of Kapton Film.

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The "lifetime" of the QUV specimens is less than 1/3 that of the comparable water immersion specimens.

Figures 16 and 17 illustrate the position of the QUV (plotted at T = 60°C) data relative to the unstressed water immersion data and the stressed humidity data on an Arrhenius plot. It is apparent from these figures that the rate of degradation observed in the cyclic UV-humidity condition is approximately equivalent to that which would occur at 80°C in the unstressed water condition. Since 1/3 of the QUV condition is simply condensing humidity at 60°C, it can be concluded that the acceleration in the QUV degradation rate is due to the dry ultraviolet portion of the cycle, during which time the temperature ranges between 50 and 55°C.
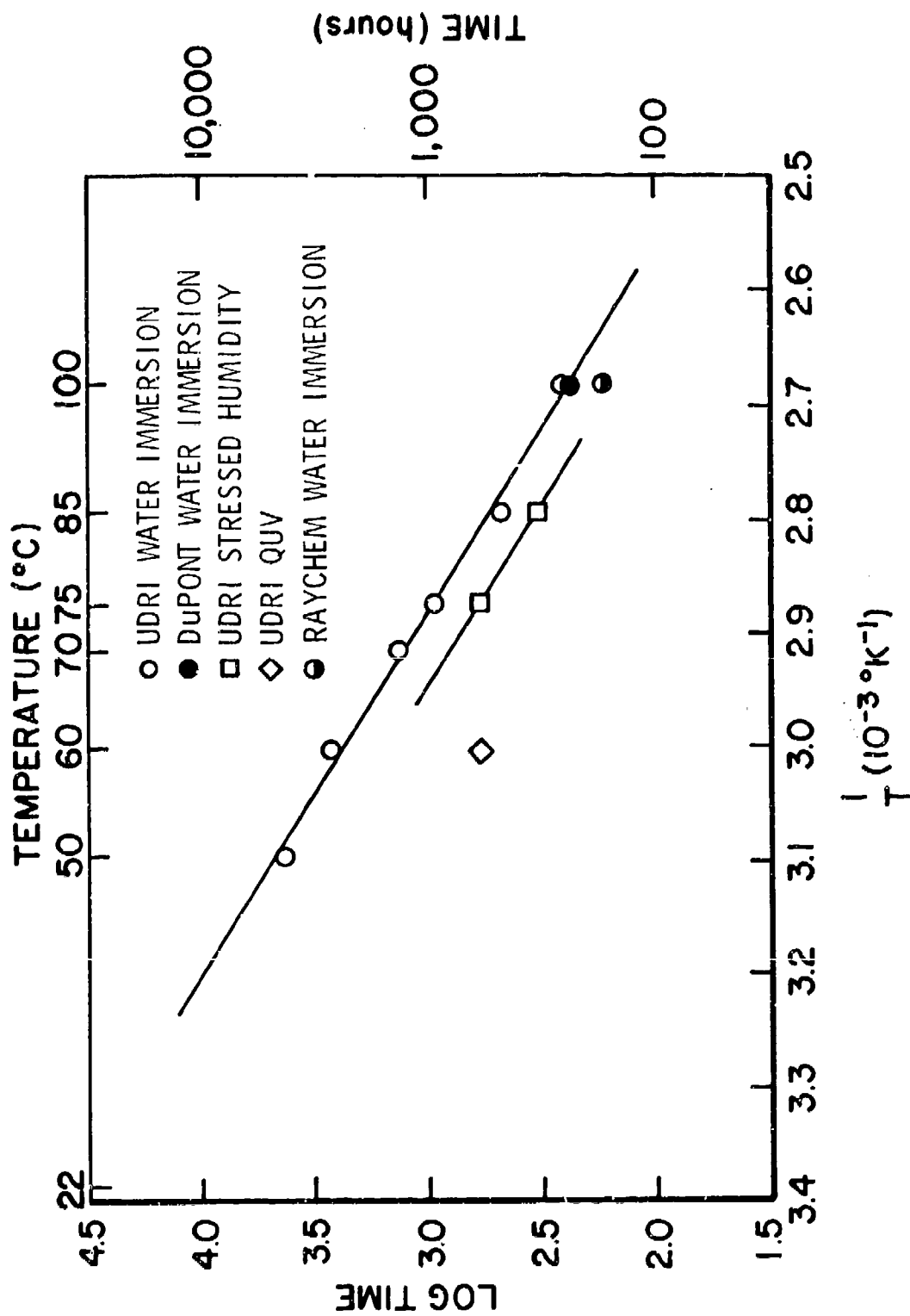
Figure 16. Effect of Temperature Upon Lifetime (20% Decrease in Tensile Strength) of Kapton Film.
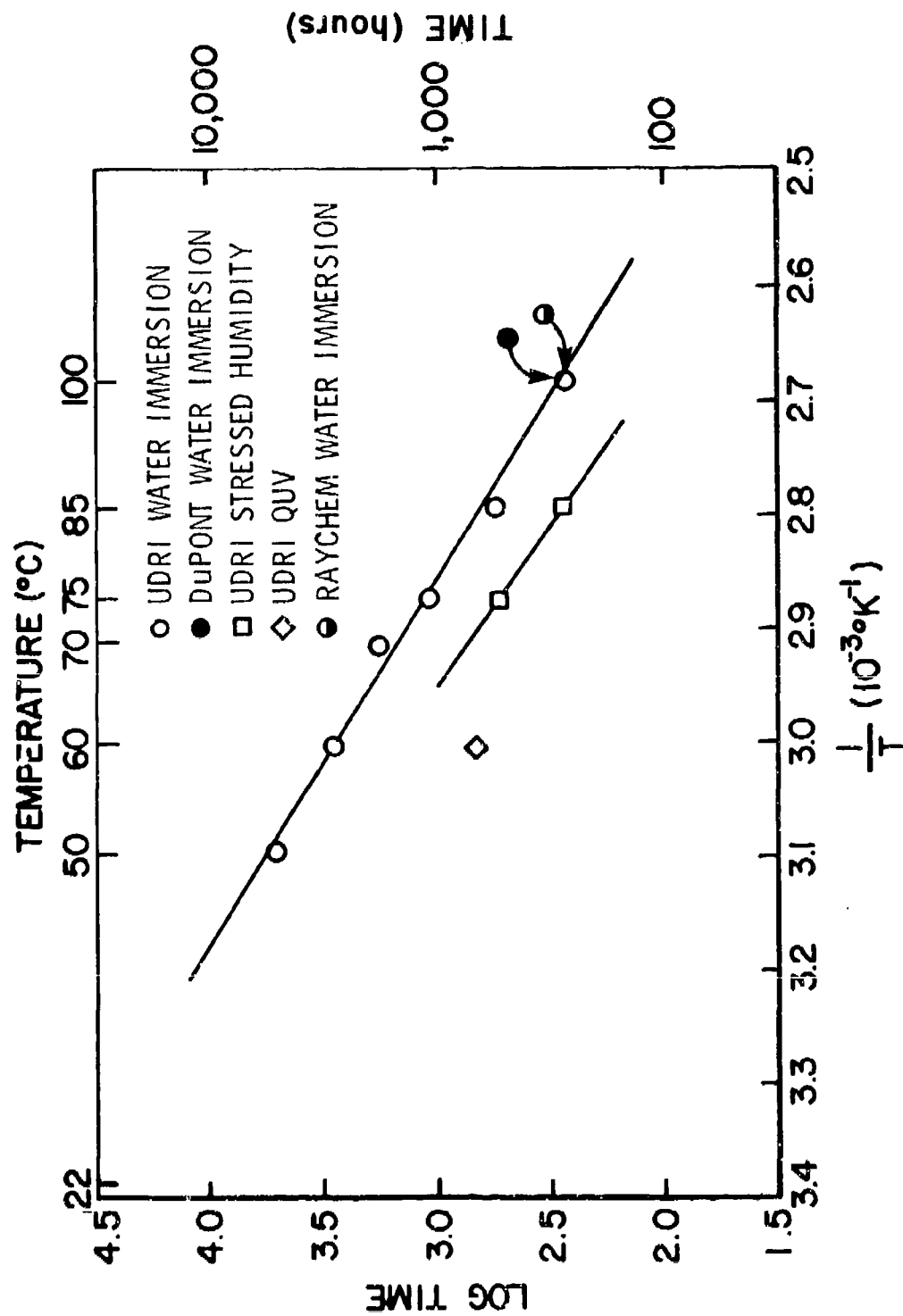
Figure 17. Effect of Temperature Upon Lifetime (50% Decrease in Tensile Elongation) of Kapton Film.

SECTION 7

CONCLUSIONS

Kapton type H film undergoes hydrolytic degradation at a rate which was found to be very well correlated to temperature by the Arrhenius relationship. Data from three previous studies[2-4] were examined and compared to that generated in this investigation. The rates of degradation determined in one of these prior studies were found to disagree considerably in magnitude from those found in the other two. The results obtained in this investigation agreed rather well with the latter two. A similar temperature dependency was found for both the results obtained here and those which exhibited the considerably different degradation rates.

While the hydrolytic degradation mechanism is not fully known and can involve a number of different degradation routes, the residual tensile strength and elongation were found to be best represented mathematically by an exponential decay function of time (first order reaction kinetics).

While the temperature range over which this data was generated was 50°C to 100°C, the excellent linearity of the Arrhenius relationship would indicate that it should be possible to extrapolate the relationship for limited distances with reasonable confidence.

The rate of degradation of Kapton H film was found to be accelerated by the imposition of a 5,000 psi (34.5 MPa) tensile stress on the film during humid aging. It was also found that the effect of temperature (over the limited temperature range examined) on degradation rate of the stressed exposures was the same as that observed for the unstressed exposures.

The rate of degradation of Kapton II film was found to be significantly accelerated by a cyclic ultraviolet-humidity exposure. This acceleration was due to the ultra-violet portion of the exposure cycle.

## REFERENCES

1. Trademark, E. I. DuPont DeNemours, Inc.

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5. Welch, G. L. and L. R. Lofgreen, "Using Accelerated Hydrolytic Reversion Data to Predict Service Life of Elastomeric Potting Compounds," AFML-TR-70-297, February 1971.

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7. Chartoff, R. P. and T. W. Chin, "A Study of Crosslinking in Polyimides by Viscoelastic and Diffusion Techniques," Polymer Engineering and Science, Vol. 20, No. 4, March 1980.

8. Wallach, M. L., Journal of Polymer Science, A-2, 953 (1968).

# APPENDIX

## COMPLETE TEST DATA

Tables A.1 through A.10 presents the complete tensile test data obtained during this program. Values labeled N.G. represent specimens which failed at the grip edge during tensile testing and which produced strength or elongation values lower than the average values.

Table A.11 presents tensile data presented by DuPont from the same mill roll as that from which all our specimens came.

The average values presented at the bottom of each column of data in these tables are summarized in the text.

TABLE A.1

CONTROL PROPERTIES OF UNAGED KAPTON FILM

| Specimen No. | ROLL C | | | ROLL D | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
| 1 | 36.0 | 65.0 | | 29.5 | 39.0 | | | | | | | |
| 2 | 33.7 | 59.0 | | 34.3 | 61.0 | | | | | | | |
| 3 | 32.5 | 51.0 | | 36.7 | 73.0 | | | | | | | |
| 4 | 32.2 | 46.0 | | 27.8 | 31.0 | | | | | | | |
| 5 | 31.6 | 44.0 | | 29.4 | 39.0 | | | | | | | |
| 6 | 25.2 | 56.0 | | 36.0 | 70.0 | | | | | | | |
| 7 | 36.0 | 64.0 | | 32.7 | 54.0 | | | | | | | |
| 8 | 35.2 | 56.0 | | 33.5 | 56.0 | | | | | | | |
| 9 | 33.6 | 48.0 | | 31.0 | 45.0 | | | | | | | |
| 10 | 37.8 | 64.0 | | 37.5 | 74.0 | | | | | | | |
| 11 | 34.0 | 47.0 | | 31.5 | 49.0 | | | | | | | |
| 12 | 33.5 | 50.0 | | 32.3 | 52.0 | | | | | | | |
| 13 | 38.5 | 69.0 | | 33.3 | 57.0 | | | | | | | |
| 14 | 31.3 | 34.0 | | 28.2 | 34.0 | | | | | | | |
| 15 | 33.7 | 49.0 | | 32.3 | 54.0 | | | | | | | |
| 16 | 35.2 | 56.0 | | 32.7 | 54.0 | | | | | | | |
| 17 | 36.5 | 62.0 | | 31.5 | 46.0 | | | | | | | |
| 18 | 35.0 | 57.0 | | 33.5 | 55.0 | | | | | | | |
| 19 | 36.3 | 63.0 | | 35.0 | 60.0 | | | | | | | |
| 20 | 32.3 | 44.0 | | 33.4 | 54.0 | | | | | | | |
| 21 | 34.5 | 48.0 | | 32.4 | 51.0 | | | | | | | |
| 22 | 37.3 | 58.0 | | 31.6 | 51.0 | | | | | | | |
| 23 | 37.2 | 59.0 | | 33.0 | 55.0 | | | | | | | |
| 24 | 36.6 | 58.0 | | 32.0 | 49.0 | | | | | | | |
| 25 | 36.5 | 59.0 | | 35.4 | 64.0 | | | | | | | |
| 26 | 34.5 | 49.0 | | 32.6 | 50.0 | | | | | | | |
| 27 | 31.0 | 38.0 | | 32.6 | 54.0 | | | | | | | |
| 28 | 34.1 | 52.0 | | 34.6 | 63.0 | | | | | | | |
| 29 | 32.1 | 44.0 | | 33.0 | 54.0 | | | | | | | |
| 30 | 35.5 | 58.0 | | 33.3 | 58.0 | | | | | | | |
| 31 | 35.2 | 58.0 | | | | | | | | | | |
| 32 | | | | | | | | | | | | |
| Avg. | 34.5 | 54.2 | | 32.6 | 52.9 | | | | | | | |
| St. Dev. | 2.0 | 3.0 | | 2.6 | 11.8 | | | | | | | |

(1) Each roll represents an adjacent slit lane from Mill Roll 07792.

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## TABLE A.2

## RESIDUAL PROPERTIES OF KAPTON FILM AFTER WATER IMMERSION AT 100°C

| Specimen No. | 24 Hr Immersion | | | 112 Hr Immersion | | | 184 Hr Immersion | | | 376 Hr Immersion | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
| 1 | 28.4 | 30 | | 30.7 | 43 | | 26.1 | 19 | N.G. | 27.7 | 28 | |
| 2 | 31.7 | 42 | | 27.4 | 28 | | 29.3 | 30 | | 27.2 | 25 | |
| 3 | 33.6 | 51 | | 24.5 | 18 | | 28.0 | 24 | | 28.0 | 30 | |
| 4 | 31.1 | 40 | | 27.9 | 30 | N.G. | 28.3 | 28 | | 22.9 | 13 | |
| 5 | 31.5 | 44 | | 26.9 | 27 | | 27.3 | 24 | | 27.1 | 26 | |
| 6 | 28.8 | 30 | N.G. | 26.2 | 24 | | 27.0 | 26 | N.G. | 28.1 | 30 | |
| 7 | 29.5 | 36 | | 29.3 | 40 | | 28.9 | 30 | | 27.0 | 26 | |
| 8 | 32.6 | 46 | | 26.4 | 28 | N.G. | 27.6 | 29 | | 25.2 | 13 | |
| 9 | 32.7 | 46 | | 27.6 | 35 | N.G. | 28.8 | 34 | | 25.3 | 18 | N.G. |
| 10 | 31.5 | 43 | | 24.6 | 22 | | 29.0 | 32 | | 27.3 | 24 | |
| 11 | 32.7 | 48 | | 26.5 | 26 | | 29.0 | 32 | | 27.0 | 27 | |
| 12 | 31.9 | 43 | | 27.6 | 32 | | 29.1 | 32 | | 26.9 | 26 | |
| 13 | 31.1 | 42 | | 25.7 | 22 | | 26.4 | — | N.C. | 27 | 26 | |
| 14 | 34.2 | 54 | | 26.9 | 30 | N.C. | 28.2 | 28 | | 27.6 | 28 | |
| 15 | 30.6 | 40 | | 26.2 | 28 | N.G. | 28.9 | 28 | | 26.1 | 23 | N.G. |
| 16 | 32.6 | 48 | | 28.8 | 36 | | 28.0 | 26 | | 27.0 | 26 | |
| 17 | 28.5 | 34 | | 27.4 | 28 | N.G. | 29.2 | 28 | N.G. | 25.0 | 19 | N.G. |
| 18 | 27.8 | 33 | | 28.2 | 34 | | 29.0 | 30 | | 24.2 | 17 | N.G. |
| 19 | 34.6 | 56 | | 28.3 | 30 | | 27.5 | 22 | | 25.6 | 22 | |
| 20 | 32.4 | 46 | | 27.6 | 34 | | 27.8 | 26 | | 25.9 | 23 | |
| 21 | 32.9 | 49 | | 28.6 | 32 | | 24.0 | 16 | | 25.0 | 22 | N.C. |
| 22 | | | | 29.0 | 36 | N.C. | 25.1 | 20 | N.G. | 25.1 | 22 | |
| 23 | | | | 26.9 | 23 | | 26.2 | 22 | N.G. | 25.2 | 22 | |
| 24 | | | | 30.0 | 41 | | 27.1 | 24 | | 23.0 | 14 | N.G. |
| 25 | | | | 28.0 | 35 | N.G. | 28.6 | 28 | | 26.2 | 25 | |
| 26 | | | | 30.0 | 42 | | 28.8 | 28 | | 27.3 | 30 | |
| 27 | | | | 27.1 | 27 | N.G. | 29.3 | 30 | | | | |
| 28 | | | | 29.3 | 37 | | | | | | | |
| 29 | | | | 29.2 | 36 | | | | | | | |
| 30 | | | | | | | | | | | | |
| 31 | | | | | | | | | | | | |
| 32 | | | | | | | | | | | | |
| Avg. | 31.6 | 44 | | 28.0 | 33 | | 28.2 | 28 | | 26.5 | 25 | |
| Std.Dev. | 1.9 | 7 | | 1.6 | 7 | | 1.2 | 4 | | 1.3 | 4 | |

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## TABLE A.3

## RESIDUAL PROPERTIES OF KAPTON FILM AFTER WATER IMMERSION AT 85°C

| Specimen No. | 200 Hr. Immersion | | | 600 Hr. Immersion | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
| 1 | 29.3 | 38 | | 27.8 | 30.6 | | | | | | | |
| 2 | 29.3 | 37 | | 26.1 | 24.0 | | | | | | | |
| 3 | 30.3 | 43 | | 25.0 | 20.0 | | | | | | | |
| 4 | 27.8 | 32 | | 26.7 | 26.8 | | | | | | | |
| 5 | 29.8 | 43 | | 27.2 | 31.8 | | | | | | | |
| 6 | 29.4 | 39 | | 25.8 | 26.4 | | | | | | | |
| 7 | 30.4 | 44 | | 25.4 | 24.6 | | | | | | | |
| 8 | 30.2 | 41 | | 24.9 | 19.2 | N.G. | | | | | | |
| 9 | 30.3 | 42 | | 26.4 | 28.2 | | | | | | | |
| 10 | 29.6 | 40 | | 27.7 | 30.0 | | | | | | | |
| 11 | 28.5 | 35 | N.G. | 26.1 | 22.2 | | | | | | | |
| 12 | 30.0 | 42 | | 26.1 | 22.0 | | | | | | | |
| 13 | 29.4 | 38 | | 26.8 | 26.2 | | | | | | | |
| 14 | 30.8 | 46 | | 26.9 | 30.4 | | | | | | | |
| 15 | 28.9 | 37 | N.G. | 26.1 | 22.8 | | | | | | | |
| 16 | 27.4 | 27 | | 26.7 | 25.2 | | | | | | | |
| 17 | 30.2 | 43 | | 28.2 | 31.3 | | | | | | | |
| 18 | 28.5 | 35 | N.G. | 27.3 | 28.6 | | | | | | | |
| 19 | 30.3 | 46 | | 26.7 | 26.6 | | | | | | | |
| 20 | 27.3 | 26 | N.G. | 26.4 | 24.0 | | | | | | | |
| 21 | 31.8 | 47 | | 24.9 | 21.8 | | | | | | | |
| 22 | 30.3 | 41 | | 26.9 | 28.2 | | | | | | | |
| 23 | 30.0 | 38 | | 24.3 | 18.4 | | | | | | | |
| 24 | 30.3 | 42 | | 26.8 | 27.9 | | | | | | | |
| 25 | 30.8 | 44 | | 25.1 | 21.2 | | | | | | | |
| 26 | 30.0 | 42 | | 25.2 | 20.0 | | | | | | | |
| 27 | 30.2 | 40 | | 26.2 | 26.2 | | | | | | | |
| 28 | 30.3 | 45 | | 26.8 | 27.6 | | | | | | | |
| 29 | 31.5 | 48 | | 26.6 | 27.4 | | | | | | | |
| 30 | 29.6 | 40 | | 2..- | 22.4 | | | | | | | |
| 31 | 29.0 | 38 | | 25.4 | 23.0 | | | | | | | |
| 32 | 27.5 | 33 | | 26.5 | 27.4 | | | | | | | |
| 33 | 30.3 | 44 | | | | | | | | | | |
| 34 | 29.3 | 33 | | | | | | | | | | |
| Avg. | 29.9 | 40.5 | | 26.5 | 26.2 | | | | | | | |
| σ | 1.0 | 4.8 | | 1.0 | 3.5 | | | | | | | |

## TABLE A.4

## RESIDUAL PROPERTIES OF KAPTON FILM AFTER WATER IMMERSION AT 75°C

| Specimen No. | 300 Hr. Immersion | | | 600 Hr. Immersion | | | 900 Hr. Immersion | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
| 1 | 32.2 | 47.8 | | 30.0 | 41.0 | | 27.9 | 31.6 | | | | |
| 2 | 31.3 | 45.0 | | 28.6 | 33.0 | | 28.8 | 36.5 | | | | |
| 3 | 31.8 | 49.6 | | 29.4 | 35.0 | | 27.2 | 29.2 | | | | |
| 4 | 30.7 | 41.0 | N.G. | 31.6 | 44.6 | | 27.8 | 31.0 | | | | |
| 5 | 28.2 | 23.0 | | 29.5 | 34.2 | | 27.0 | 26.4 | | | | |
| 6 | 31.1 | 44.4 | | 29.8 | 37.2 | | 28.6 | 31.2 | | | | |
| 7 | 30.7 | 52.6 | | 29.0 | 35.0 | | 26.4 | 24.0 | | | | |
| 8 | 31.5 | 46.4 | | 30.2 | 40.5 | | 28.0 | 31.0 | | | | |
| 9 | 32.3 | 53.0 | | 30.4 | 40.0 | | 29.7 | 37.6 | | | | |
| 10 | 31.2 | 44.0 | | 27.0 | 27.0 | | 27.2 | 27.5 | N.G. | | | |
| 11 | 30.1 | 36.0 | N.G. | 28.2 | 32.5 | | 27.7 | 28.6 | | | | |
| 12 | 31.6 | 43.0 | | 29.5 | 33.0 | | 27.8 | 28.2 | | | | |
| 13 | 32.7 | 50.6 | | 29.0 | 34.0 | | 26.3 | 23.0 | N.G. | | | |
| 14 | 30.0 | 38.0 | | 29.5 | 38.2 | | 28.0 | 28.5 | | | | |
| 15 | 30.1 | 40.0 | | 31.0 | 43.0 | | 27.1 | 24.2 | N.G. | | | |
| 16 | 29.3 | 35.0 | | 29.2 | 38.0 | | 27.2 | 26.8 | | | | |
| 17 | 30.1 | 40.6 | N.G. | 30.8 | 45.0 | | 26.3 | 23.0 | N.G. | | | |
| 18 | 31.1 | 46.0 | | 29.5 | 39.5 | | 28.3 | 31.5 | | | | |
| 19 | 31.8 | 48.5 | | 30.2 | 41.8 | | 28.1 | 31.0 | | | | |
| 20 | 28.2 | 30.5 | | 26.2 | 23.5 | | 26.2 | 23.5 | N.G. | | | |
| 21 | 29.3 | 34.0 | | 30.2 | 45.0 | | 25.3 | 21.4 | N.G. | | | |
| 22 | 27.7 | 27.6 | | 31.0 | 45.0 | | 27.4 | 30.2 | | | | |
| 23 | 29.4 | 37.4 | | 25.0 | 22.2 | | 25.8 | 23.0 | N.G. | | | |
| 24 | 33.2 | 55.5 | | 29.2 | 38.2 | | 26.6 | 29.0 | N.G. | | | |
| 25 | 28.3 | 31.6 | | 30.8 | 44.5 | | 26.2 | 25.0 | | | | |
| 26 | 29.2 | 37.2 | | | | | 25.5 | 22.0 | N.G. | | | |
| 27 | 31.1 | 46.0 | | | | | 26.5 | 25.2 | | | | |
| 28 | 32.6 | 54.0 | | | | | 28.5 | 34.3 | | | | |
| 29 | 32.1 | 52.0 | | | | | 29.2 | 39.5 | | | | |
| 30 | 29.6 | 41.0 | | | | | 23.0 | 34.0 | | | | |
| Avg. | 30.6 | 42.0 | | 29.5 | 37.8 | | 27.8 | 30.3 | | | | |
| s.d. | 1.5 | 7.8 | | 1.3 | 6.1 | | 0.9 | 4.2 | | | | |

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## TABLE A.5

### RESIDUAL PROPERTIES OF KAPTON FILM AFTER WATER IMMERSION AT 70°C

| Specimen No. | 500 Hr. Immersion | | | 1000 Hr. Immersion | | | 1500 Hr. Immersion | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result |
| 1 | 31.6 | 44.0 | N.G. | 31.3 | 46.2 | | 26.8 | 26.6 | N.G. | | | |
| 2 | 33.6 | 53.6 | | 30.8 | 46.4 | | 28.5 | 39.0 | | | | |
| 3 | 32.8 | 49.2 | | 28.1 | 33.6 | | 27.1 | 29.2 | | | | |
| 4 | 32.0 | 46.0 | | 28.9 | 39.2 | | 27.8 | 32.4 | | | | |
| 5 | 29.4 | 49.0 | | 26.3 | 26.0 | | 27.2 | 27.2 | | | | |
| 6 | 26.6 | 40.0 | N.G. | 27.2 | 32.6 | | 27.2 | 28.4 | | | | |
| 7 | 30.5 | 69.0 | | 29.2 | 42.8 | | 25.8 | 21.4 | | | | |
| 8 | 30.0 | 44.0 | N.G. | 27.6 | 32.0 | | 27.8 | 27.0 | N.G. | | | |
| 9 | 29.4 | 39.0 | | 29.8 | 39.6 | | 27.2 | 24.0 | | | | |
| 10 | 34.0 | 54.0 | | 30.2 | 43.4 | | 28.4 | 34.0 | | | | |
| 11 | 30.5 | 39.0 | | 26.3 | 25.2 | | 28.0 | 30.0 | | | | |
| 12 | 30.2 | 40.0 | | 30.5 | 45.6 | | 28.5 | 34.8 | | | | |
| 13 | 30.3 | 40.0 | | 28.7 | 37.2 | | 28.8 | 33.6 | | | | |
| 14 | 30.3 | 42.0 | | 28.8 | 40.0 | | 26.7 | 25.0 | | | | |
| 15 | 32.5 | 51.0 | | 28.5 | 39.0 | | 26.3 | 24.0 | | | | |
| 16 | 28.0 | 31.0 | | 24.8 | 20.0 | | 27.9 | 32.2 | | | | |
| 17 | 29.5 | 38.0 | | 29.7 | 44.8 | | 26.5 | 23.6 | | | | |
| 18 | 31.5 | 46.8 | | 28.9 | 38.8 | | 27.9 | 30.8 | | | | |
| 19 | 33.6 | 59.2 | | 27.9 | 34.0 | | 29.2 | 37.2 | | | | |
| 20 | 32.6 | 53.4 | | 30.4 | 46.6 | | 29.2 | 36.4 | | | | |
| 21 | 31.6 | 49.0 | | 26.5 | 28.0 | | 28.3 | 32.4 | | | | |
| 22 | 31.6 | 47.0 | | 27.7 | 34.8 | | 25.6 | 22.0 | | | | |
| 23 | 26.0 | 22.0 | | 29.1 | 42.0 | | 26.6 | 27.8 | | | | |
| 24 | 31.5 | 46.0 | | 29.8 | 44.8 | | 26.2 | 23.4 | | | | |
| 25 | 29.4 | 33.6 | | 27.6 | 35.5 | | 29.1 | 39.4 | | | | |
| 26 | 32.0 | 47.0 | | 29.7 | 45.8 | | 28.1 | 34.8 | | | | |
| 27 | 29.5 | 39.6 | | 28.7 | 39.4 | | 26.2 | 24.8 | | | | |
| 28 | 30.6 | 45.6 | | 26.9 | 30.4 | | 27.4 | 29.8 | | | | |
| 29 | 27.0 | 27.0 | | 26.5 | 31.8 | | 28.2 | 28.0 | | | | |
| 30 | 32.0 | 50.0 | | 28.8 | 43.2 | | 28.8 | 36.6 | | | | |
| 31 | 31.4 | 46.0 | | 27.2 | 35.0 | | 28.1 | 32.0 | | | | |
| 32 | | | | | | | 26.8 | 27.4 | | | | |
| | | | | | | | 27.0 | | | | | |
| Avg. | 31.0 | 45.9 | | 28.7 | 37.7 | | 27.6 | 29.9 | | | | |
| Std. Dev. | 2.0 | 10.? | | 1.7 | 7.6 | | 1.1 | 5.3 | | | | |

# TABLE 2.6

## RESIDUAL PROPERTIES OF KAPTON FILM AFTER WATER IMMERSION AT 60°C

| Specimen No. | Hr. Immersion Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | 1500 Hr. Immersion Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Hr. Immersion Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | 3000 Hr. Immersion Tensile Strength (10³psi) | Ult. Elong. (%) | Test Length | 4 Hr. Immersion Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 27.8 | 31.0 | | 28.0 | 29.0 | N.G. | 28.5 | 14.6 | N.G. | 27.9 | 33.5 | | 27.5 | 17 | |
| 2 | 30.3 | 47.2 | | 27.8 | 28.0 | | 26.9 | 23.4 | | 28.1 | 33.0 | | 25.7 | 22 | |
| 3 | 28.2 | 32.6 | | 28.8 | 32.0 | N.G. | 28.4 | 33.0 | | 24.8 | 25.4 | | 25.8 | 20 | N.G. |
| 4 | 31.0 | 41.4 | | 28.7 | 28.0 | | 27.5 | 33.5 | | 27.5 | 27.5 | | 25.4 | 26 | |
| 5 | 30.2 | 43.4 | | 29.2 | 34.0 | N.G. | 28.4 | 26.5 | N.G. | 26.4 | 24.6 | N.G. | 26.5 | 19 | N.G. |
| 6 | 26.1 | 31.4 | | 24.3 | 15.0 | | 27.0 | 24.2 | N.G. | 27.4 | 25.0 | | 27.8 | 19 | N.G. |
| 7 | 31.1 | 46.2 | | 26.0 | 21.0 | | 28.7 | 32.4 | | 27.2 | 28.0 | | 29.1 | 25 | |
| 8 | 30.3 | 40.4 | | 28.4 | 34.0 | | 28.4 | 36.5 | | 27.4 | 20.0 | | 28.3 | 14 | |
| 9 | 30.8 | 46.8 | | 27.0 | 26.0 | | 27.6 | 24.0 | | 23.3 | 14.2 | | 28.2 | 22 | |
| 10 | 27.0 | 31.6 | | 28.3 | 32.0 | | 26.8 | 25.5 | | 25.3 | 21.9 | | 27.3 | 26 | |
| 11 | 30.3 | 42.9 | | 29.9 | 40.0 | | 27.3 | 26.8 | N.G. | 26.7 | 27.2 | | 26.2 | 20 | N.G. |
| 12 | 31.2 | 48.0 | | 28.4 | 35.0 | | 28.5 | 31.8 | | 27.3 | 31.4 | | 26.9 | 20 | N.G. |
| 13 | 31.1 | 48.2 | | 29.3 | 37.0 | | 26.0 | 24.6 | N.G. | 25.8 | 23.0 | | 25.2 | 20 | N.G. |
| 14 | 30.5 | 43.0 | | 29.5 | 57.0 | | 27.0 | 29.0 | | 28.3 | 27.9 | | 20.0 | 16 | |
| 15 | 30.6 | 57.0 | | 29.6 | 38.0 | | 25.9 | 20.8 | N.G. | 25.8 | 23.5 | | 25.8 | 28 | |
| 16 | 31.3 | 47.2 | | 30.6 | 42.0 | | 28.0 | 25.7 | | 27.2 | 29.8 | | 25.2 | 16 | |
| 17 | 30.2 | 42.6 | | 29.5 | 37.0 | | 25.2 | 20.6 | N.G. | 27.5 | 30.5 | | 24.0 | 14 | |
| 18 | 30.3 | 49.4 | | 28.0 | 26.0 | | 23.2 | 33.4 | | 27.0 | 27.2 | | 25.1 | 16 | |
| 19 | 27.7 | 34.4 | | 28.6 | 33.0 | | 24.8 | 17.5 | | 26.3 | 26.8 | | 28.2 | 24 | |
| 20 | 30.4 | 49.8 | | 28.4 | 33.0 | | 26.0 | 26.2 | | 25.0 | 18.5 | | 26.0 | 19 | N.G. |
| 21 | 29.1 | 40.0 | | 28.7 | 35.0 | | 26.1 | 24.2 | | 27.2 | 29.6 | | 28.3 | 14 | |
| 22 | 27.5 | 31.4 | | 30.2 | 44.0 | | 28.3 | 36.8 | | 27.2 | 27.6 | | 28.1 | 23 | |
| 23 | 29.5 | 41.6 | | 29.0 | 35.0 | | 24.4 | 29.0 | N.G. | 27.0 | 27.5 | N.G. | 31.2 | 33 | |
| 24 | 31.1 | 46.0 | | 30.4 | 39.0 | | 26.2 | 24.6 | | 24.2 | 16.5 | | 31.5 | 16 | |
| 25 | 31.3 | 49.4 | | 30.5 | 41.0 | | 28.4 | 36.6 | N.G. | | | | 27.2 | 22 | |
| 26 | 28.2 | 37.0 | | 29.1 | 38.0 | | 27.4 | 32.0 | | | | | 27.3 | 20 | |
| 27 | 31.2 | 49.8 | | 28.7 | 33.0 | | 26.8 | 25.4 | | | | | 25.1 | 22 | |
| 28 | 31.2 | 52.6 | | 26.6 | 23.0 | | 27.7 | 30.0 | | | | | 27.0 | 21 | |
| 29 | 30.9 | 46.9 | | 28.3 | 32.0 | | 26.1 | 36.8 | | | | | 24.2 | 17 | |
| 30 | 25.3 | 23.0 | | 27.5 | 29.0 | | 25.9 | 22.5 | | | | | | | |
| 31 | 30.2 | 37.4 | | 29.4 | 37.0 | | 25.7 | 24.8 | | | | | | | |
| 32 | 30.9 | 38.2 | | 27.0 | 26.0 | | 28.6 | 32.6 | | | | | | | |
| 33 | 30.2 | 41.0 | | 28.7 | 34.0 | | 27.8 | 25.7 | | | | | | | |
| 34 | 27.5 | 31.0 | | 26.9 | 30.0 | | 33.3 | 38.2 | | | | | | | |
| 35 | 31.1 | | | 28.0 | 28.0 | | 30.0 | 36.0 | | | | | | | |
| Avg. | 30.1 | 41.3 | | 28.6 | 33.4 | | 27.3 | 26.5 | | 26.7 | 27.1 | | 26.7 | 21.6 | |
| σ | 1.4 | 6.8 | | 1.3 | 7.1 | | 1.0 | 27.2 | | 1.2 | | | 1.2 | | |

## TABLE A.7

## RESIDUAL PROPERTIES OF KAPTON FILM AFTER WATER IMMERSION AT 50°C

| Specimen No. | 1000 Hr. Immersion | | | 2000 Hr. Immersion | | | 3500 Hr. Immersion | | | 4500 Hr. Immersion | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
| 1 | 27.4 | 22.0 | | 31.2 | 43.8 | | 28.7 | 33.6 | | | | |
| 2 | 30.7 | 40.4 | | 28.8 | 30.6 | | 31.7 | 41.4 | | | | |
| 3 | 31.7 | 50.0 | | 32.2 | 53.6 | | 30.1 | 40.0 | | | | |
| 4 | 30.9 | 45.4 | | 26.6 | 27.0 | | 29.8 | 32.6 | | | | |
| 5 | 29.1 | 40.0 | | 31.1 | 48.8 | | 30.2 | 41.0 | | | | |
| 6 | 31.7 | 50.0 | | 30.2 | 43.5 | | 27.6 | 35.0 | N.G. | | | |
| 7 | 26.4 | 27.0 | | 30.5 | 45.5 | | 29.3 | 43.2 | | | | |
| 8 | 33.0 | 58.4 | | 29.9 | 40.5 | | 29.3 | 30.4 | | | | |
| 9 | 29.7 | 43.0 | | 28.2 | 30.6 | | 24.8 | 21.0 | | | | |
| 10 | 30.7 | 47.6 | | 30.2 | 40.5 | | 27.3 | 29.5 | | | | |
| 11 | 27.5 | 33.2 | | 29.9 | 38.8 | | 22.9 | 42.6 | | | | |
| 12 | 31.2 | 50.0 | | 30.8 | 43.0 | | 30.2 | 41.5 | | | | |
| 13 | 30.2 | 45.0 | N.G. | 30.1 | 41.4 | | 29.0 | 38.4 | | | | |
| 14 | 30.5 | 47.6 | | 30.2 | 42.4 | | 26.3 | 25.4 | | | | |
| 15 | 30.3 | 41.4 | | 29.6 | 42.0 | | 29.5 | 44.0 | | | | |
| 16 | 33.3 | 54.0 | | 32.3 | 52.6 | | 30.0 | 47.0 | | | | |
| 17 | 38.8 | 35.2 | | 28.2 | 30.2 | N.G. | 28.8 | 40.6 | | | | |
| 18 | 32.7 | 50.6 | | 31.3 | 43.2 | | 29.8 | 37.5 | | | | |
| 19 | 32.2 | 50.0 | | 28.7 | 31.0 | | 27.2 | 27.6 | | | | |
| 20 | 33.0 | 55.4 | | 32.3 | 52.2 | | 28.3 | 30.6 | | | | |
| 21 | 31.8 | 51.2 | | 32.8 | 51.0 | | 28.2 | 30.3 | | | | |
| 22 | 27.3 | 32.4 | | 32.3 | 49.4 | | 30.0 | 39.4 | | | | |
| 23 | 31.7 | 53.2 | | 30.9 | 42.0 | | 30.3 | 40.0 | | | | |
| 24 | 30.2 | 47.4 | | 30.7 | 38.6 | | 30.6 | 42.0 | | | | |
| 25 | 27.8 | 37.0 | | 29.8 | 39.8 | | 30.5 | 4.0 | | | | |
| 26 | 31.2 | 49.6 | | 29.1 | 34.6 | | 29.0 | 17.8 | | | | |
| 27 | 30.7 | 49.4 | | 27.4 | 36.0 | | 26.2 | 24.8 | | | | |
| 28 | 29.4 | 42.8 | | 31.2 | 46.2 | | 27.4 | 31.0 | | | | |
| 29 | 30.5 | 45.0 | | 32.2 | 51.8 | | 28.7 | 36.4 | | | | |
| 30 | 32.6 | 56.0 | | 31.8 | 49.0 | | | | | | | |
| 31 | 29.6 | 42.6 | | 30.7 | 44.8 | | | | | | | |
| 32 | | | | 30.1 | 46.0 | | | | | | | |
| 33 | | | | 30.9 | 43.4 | | | | | | | |
| 34 | | | | 31.4 | 51.5 | | | | | | | |
| 35 | | | | 30.1 | 40.8 | | | | | | | |
| 36 | | | | 32.4 | 56.2 | | | | | | | |
| AVG. | 30.6 | 45.2 | | 30.3 | 42.1 | | 28.9 | 36.3 | | | | |
| S.D. | 2.0 | 8.2 | | 1.5 | 7.7 | | 1.6 | 7.2 | | | | |

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## TABLE A.8

RESIDUAL PROPERTIES OF KAPTON FILM AFTER UNSTRESSED EXPOSURE TO
ULTRAVIOLET AND HUMIDITY IN QUV CABINET

| Specimen No. | 200 Hr. Exposure | | | 500 Hr. Exposure | | | 1000 Hr. Exposure | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (lb/in) | Ult. Elong. (%) | Test Results | Tensile Strength (lb/in) | Ult. Elong. (%) | Test Results | Tensile Strength (lb/in) | Ult. Elong. (%) | Test Results | Tensile Strength (lb/in) | Ult. Elong. (%) | Test Results |
| 1 | 32.4 | 44.8 | | 27.8 | 26.4 | | 24.1 | 17.0 | | | | |
| 2 | 35.1 | 50.2 | | 31.0 | 40.2 | | 24.5 | 19.4 | | | | |
| 3 | 32.3 | 43.6 | | 23.3 | 13.8 | | 23.2 | 16.4 | | | | |
| 4 | 32.3 | 55.2 | | 29.8 | 35.6 | | 22.3 | 17.0 | | | | |
| 5 | 32.7 | 57.0 | | 28.2 | 34.3 | | 22.2 | 17.4 | | | | |
| 6 | 32.1 | 54.6 | | 24.7 | 20.5 | N.G. | 23.0 | 16.9 | | | | |
| 7 | 32.5 | 55.0 | | 27.9 | 34.2 | | 22.4 | 15.0 | | | | |
| 8 | 30.3 | 42.2 | | 24.4 | 19.0 | N.G. | 22.8 | 16.2 | | | | |
| 9 | 30.2 | 39.8 | | 27.2 | 28.8 | N.G. | 23.1 | 19.3 | | | | |
| 10 | 32.1 | 49.0 | | 27.8 | 32.0 | | 21.4 | 13.0 | N.G. | | | |
| 11 | 30.3 | 41.8 | | 26.7 | 27.6 | N.G. | 23.1 | 16.8 | N.G. | | | |
| 12 | 32.3 | 51.4 | | 27.4 | 22.4 | N.G. | 22.8 | 17.7 | | | | |
| 13 | 29.8 | 41.2 | | 29.0 | 34.8 | | 23.2 | 18.9 | | | | |
| 14 | 31.6 | 46.8 | N.G. | 27.0 | 35.4 | | 22.0 | 15.0 | N.G. | | | |
| 15 | 33.0 | 51.2 | | 29.2 | 39.4 | | 21.9 | 15.5 | | | | |
| 16 | 31.7 | 49.2 | | 26.3 | 29.4 | | 23.5 | 21.0 | | | | |
| 17 | 32.9 | 50.0 | | 28.8 | 37.2 | | 22.3 | 19.0 | | | | |
| 18 | 30.2 | 38.6 | | 28.7 | 36.8 | | 22.2 | 16.3 | N.G. | | | |
| 19 | 31.4 | 43.0 | | 29.4 | 38.4 | | 23.4 | 19.4 | | | | |
| 20 | 32.1 | 44.5 | | 28.8 | 37.0 | | 22.7 | 16.6 | N.G. | | | |
| 21 | 34.2 | 58.8 | | 38.2 | 31.2 | N.G. | 21.0 | 17.0 | N.G. | | | |
| 22 | 32.2 | 48.6 | | 28.1 | 33.2 | | 23.9 | 17.4 | N.G. | | | |
| 23 | 30.2 | 39.8 | | 29.3 | 37.8 | | 24.4 | 19.6 | | | | |
| 24 | 31.8 | 36.8 | | 27.7 | 29.0 | | 24.0 | 23.0 | | | | |
| 25 | | | | 30.2 | 41.0 | | 22.8 | 22.0 | | | | |
| 26 | | | | 29.3 | 35.0 | | 23.9 | 19.4 | | | | |
| 27 | | | | 29.3 | 35.8 | | 24.1 | 20.0 | | | | |
| 28 | | | | 29.2 | 40.0 | | 23.5 | 18.0 | | | | |
| 29 | | | | 28.2 | 38.0 | | 24.6 | 21.0 | | | | |
| 30 | | | | 26.7 | 24.0 | | 24.1 | 19.0 | | | | |
| 31 | | | | | | | 23.1 | 21.6 | | | | |
| 32 | | | | | | | 21.2 | 14.0 | | | | |
| 33 | | | | | | | 23.0 | 20.6 | | | | |
| 34 | | | | | | | 21.4 | 13.5 | | | | |
| 35 | | | | | | | 23.4 | 17.5 | | | | |
| 36 | | | | | | | 22.8 | 18.0 | | | | |
| 37 | | | | | | | 22.7 | 16.4 | | | | |
| 38 | | | | | | | 22.7 | 17.5 | | | | |
| 39 | | | | | | | 20.8 | 19.0 | | | | |
| 40 | | | | | | | 22.1 | 20.1 | | | | |
| 41 | | | | | | | 23.8 | 22.0 | | | | |
| 42 | | | | | | | 23.4 | 18.0 | | | | |
| 43 | | | | | | | 23.3 | 16.8 | | | | |
| 44 | | | | | | | 23.7 | 19.6 | | | | |
| | | | | | | | 24.5 | 22.0 | | | | |
| | | | | | | | 24.6 | 21.6 | | | | |
| Avg. | 32.1 | 48.6 | | 29.3 | 37.0 | | 19.6 | | | | | |
| | 1.4 | 6.6 | | 1.5 | 8.5 | | | | | | | |

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# TABLE A.9

## RESIDUAL PROPERTIES OF KAPTON FILM AFTER STRESSED-HUMIDITY EXPOSURES AT 85°C

| Specimen No. | 200 Hr. Exposure | | | 400 Hr. Exposure | | | Tensile Strength ($10^3$psi) | Ult. Elong. (%) | Test Result | Tensile Strength ($10^3$psi) | Ult. Elong. (%) | Test Result |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength ($10^3$psi) | Ult. Elong. (%) | Test Result | Tensile Strength ($10^3$psi) | Ult. Elong. (%) | Test Result | | | | | | |
| 1 | 30.2 | 36.8 | | 26.6 | 16.0 | | | | | | | |
| 2 | 27.5 | 23.8 | | 25.6 | 16.0 | N.G. | | | | | | |
| 3 | 28.2 | 27.4 | | 27.0 | 22.0 | | | | | | | |
| 4 | 32.2 | 46.6 | | 27.5 | 22.0 | | | | | | | |
| 5 | 28.2 | 30.8 | | 25.4 | 15.6 | | | | | | | |
| 6 | 30.2 | 34.6 | | 29.1 | 28.0 | | | | | | | |
| 7 | 28.0 | 27.6 | | 27.0 | 20.0 | | | | | | | |
| 8 | 29.3 | 32.0 | | 28.5 | 24.0 | | | | | | | |
| 9 | 28.2 | 24.6 | N.G. | 27.2 | 23.0 | | | | | | | |
| 10 | 29.2 | 32.8 | | 27.6 | 27.0 | | | | | | | |
| 11 | 28.8 | 28.4 | | 28.0 | 23.6 | | | | | | | |
| 12 | 29.8 | 31.4 | | 26.0 | 16.0 | N.G. | | | | | | |
| 13 | 30.7 | 35.8 | | 26.5 | 19.0 | | | | | | | |
| 14 | 30.3 | 37.0 | | 23.6 | 10.0 | | | | | | | |
| 15 | 30.1 | 35.6 | | | | | | | | | | |
| 16 | 24.4 | 27.7 | | | | | | | | | | |
| 17 | 32.1 | 9.0 | N.G. | | | | | | | | | |
| 18 | 27.1 | 20.4 | | | | | | | | | | |
| 19 | 29.5 | 31.4 | | | | | | | | | | |
| 20 | 31.2 | 41.2 | | | | | | | | | | |
| 21 | 29.3 | 32.2 | | | | | | | | | | |
| 22 | 20.5 | 7.4 | | | | | | | | | | |
| 23 | 29.5 | 33.4 | | | | | | | | | | |
| Avg. | 28.7 | 31.0 | | 27.0 | 20.9 | | | | | | | |
| S.D. | 2.6 | 8.1 | | 1.4 | 5.1 | | | | | | | |

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## TABLE A.10

RESIDUAL PROPERTIES OF KAPTON FILM AFTER STRESSED-HUMIDITY EXPOSURES AT 75°C

| Specimen No. | 300 Hr. Exposure | | | 600 Hr. Exposure | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³ psi) | Ult. Elong. (%) | Test Result |
| 1 | 22.3 | 33.0 | | 28.9 | 27.8 | | | | | | | |
| 2 | 30.8 | 42.0 | | 26.8 | 18.0 | | | | | | | |
| 3 | 20.1 | 7.0 | N.G. | 28.6 | 31.6 | | | | | | | |
| 4 | 28.2 | 28.0 | | 28.5 | 30.4 | | | | | | | |
| 5 | 30.3 | 37.0 | | 29.0 | 31.0 | | | | | | | |
| 6 | 30.5 | 50.0 | | 30.7 | 39.0 | | | | | | | |
| 7 | 28.2 | 25.0 | N.G. | 27.8 | 24.5 | | | | | | | |
| 8 | 32.2 | 42.0 | | 28.2 | 31.0 | | | | | | | |
| 9 | 29.5 | 35.0 | | 27.4 | 23.0 | | | | | | | |
| 10 | 30.6 | 35.0 | | 30.1 | 34.0 | | | | | | | |
| 11 | 29.5 | 18.0 | | 16.0 | 4.0 | | | | | | | |
| 12 | 29.3 | 29.0 | | 27.7 | 22.0 | | | | | | | |
| 13 | 29.5 | 32.0 | | 29.5 | 28.2 | | | | | | | |
| 14 | 29.0 | 34.0 | | | | | | | | | | |
| 15 | 30.4 | 35.0 | | | | | | | | | | |
| 16 | 27.4 | 24.0 | | | | | | | | | | |
| 17 | 28.5 | 22.0 | | | | | | | | | | |
| 18 | 25.7 | 17.0 | N.G. | | | | | | | | | |
| 19 | 30.0 | 32.0 | | | | | | | | | | |
| 20 | 29.0 | 33.0 | | | | | | | | | | |
| 21 | 28.3 | 24.0 | | | | | | | | | | |
| 22 | 30.0 | 34.0 | | | | | | | | | | |
| 23 | 29.5 | 31.0 | | | | | | | | | | |
| 24 | 32.0 | 44.0 | | | | | | | | | | |
| 25 | 30.6 | 37.0 | | | | | | | | | | |
| 26 | 28.7 | 29.0 | | | | | | | | | | |
| 27 | 30.5 | 37.9 | | | | | | | | | | |
| 28 | 29.5 | 31.0 | | | | | | | | | | |
| 29 | 27.5 | 44.0 | | | | | | | | | | |
| 30 | 28.7 | 26.0 | | | | | | | | | | |
| 31 | 31.5 | 42.0 | | | | | | | | | | |
| 32 | 30.5 | 37.0 | | | | | | | | | | |
| 33 | 27.0 | 19.0 | | | | | | | | | | |
| 34 | 29.0 | 29.0 | | | | | | | | | | |
| 35 | 29.3 | 26.0 | | | | | | | | | | |
| Avg. | 29.6 | 32.9 | | 27.6 | 26.5 | | | | | | | |
| S.D. | 1.1 | 7.0 | | 3.7 | 8.7 | | | | | | | |

## TABLE A.11

### PROPERTIES OF UNAGED KAPTON FILM AS DETERMINED BY DUPONT

| Specimen No. | Roll A - Location 1[1] | | | Roll A - Location 2[2] | | | Roll A - Location 3[3] | | | Roll B | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result | Tensile Strength (10³psi) | Ult. Elong. (%) | Test Result |
| 1 | 35.2 | 72.0 | | 32.0 | 60.0 | | 34.8 | 69.0 | | 30.8 | 46.0 | |
| 2 | 35.6 | 75.0 | | 32.3 | 63.0 | | 35.9 | 75.0 | | 36.8 | 70.0 | |
| 3 | 32.0 | 54.0 | | 32.5 | 61.0 | | 36.0 | 75.0 | | 34.7 | 62.0 | |
| 4 | 35.9 | 75.0 | | 32.8 | 67.0 | | 32.8 | 58.0 | | 34.2 | 60.0 | |
| 5 | 35.0 | 68.0 | | 34.8 | 74.0 | | 36.8 | 80.0 | | 37.7 | 75.0 | |
| 6 | 32.9 | 62.0 | | 33.4 | 67.0 | | 34.9 | 72.0 | | 36.1 | 68.0 | |
| 7 | 35.7 | 75.0 | | 36.0 | 83.0 | | 33.6 | 65.0 | | 35.8 | 68.0 | |
| 8 | 32.3 | 57.0 | | 33.2 | 66.0 | | 36.3 | 80.0 | | 30.1 | 40.0 | |
| 9 | 30.9 | 50.0 | | 34.8 | 77.0 | | 36.7 | 78.0 | | 34.3 | 57.0 | |
| 10 | 36.4 | 79.0 | | 34.6 | 77.0 | | 37.7 | 85.0 | | 37.2 | 72.0 | |
| 11 | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | |
| 18 | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | |
| 24 | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | |
| 26 | | | | | | | | | | | | |
| 27 | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | |
| 29 | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | |
| 31 | | | | | | | | | | | | |
| 32 | | | | | | | | | | | | |
| Avg. | 34.2 | 66.7 | | 33.6 | 69.5 | | 35.6 | 73.7 | | 34.8 | 61.8 | |
| Std.Dev. | 0.24 | 10.2 | | 0.23 | 7.8 | | 0.25 | 8.0 | | 0.24 | 11.4 | |

(1) Top of roll.
(2) 100 ft. further into roll.
(3) 200 ft. further into roll.
(4) Each roll represents an adjacent slit lane (from Mill Roll 07792) to those from which the data in Table A.1 was obtained.

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